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EDITORIAL NOTES.

WE regret to have to record that our colleague, Dr. Henry Woodward, died at his home at Bushey, Herts, on 6th September, in his 89th year. He retained his active interest in our work almost until the end, and passed away peacefully in the presence of his family.

In association with the late Professor T. Rupert Jones, Dr. Woodward founded the GEOLOGICAL MAGAZINE in July, 1864, and from July, 1865, to December, 1918, he edited every number except one, which he entrusted to his nephew, the late Horace B. Woodward, when he felt overcome by the loss of his younger son in 1901. His task was, indeed, more than that of editing, for he was faced with the usual difficulty of technical periodicals—a circulation too restricted for financial success. At intervals he had to enlist the sympathy and help of generous friends, whom he found always ready to second his disinterested efforts to promote geological science by maintaining a regular serial publication.

It has been well said that since 1864 every British recruit to geology has begun his career as an author in the pages of the GEOLOGICAL MAGAZINE. Dr. Woodward's genial personality and note of encouragement were always stimulating to beginners, and even when he considered drastic editing necessary, his tactful ways usually smoothed all difficulties. His wise advice on the presentation of a subject often turned inacceptable efforts into valuable contributions, and his judicious treatment of over-eager correspondents not infrequently softened acrimonious controversies into reasonable discussions. His hospitable reception of many papers which had been refused elsewhere was by no means the least of the services he rendered to geological science as editor. He was, indeed, an impartial critic of every genuine effort to advance.

A full biography of Dr. Woodward will appear in a later number.

At the first meeting of the Advisory Committee for the Metalliferous Mining Industry the Secretary for Mines, Mr. W. C. Bridgeman, M.P., welcomed the members in an opening speech. After deploring the depressed state of the mining industry, he went on to state, in emphatic terms, that the Government could in no circumstances afford any financial assistance. One must suppose that the industry as a whole does not command enough votes to be of any importance for electoral purposes. It would be a matter of much interest to compare the amounts of public money spent on coal mining and metalliferous mining respectively. With one portion of the speech we are in hearty agreement: "he thought that the mining industry in this country had suffered in the past from an insufficient acquaintance with geological information in regard to all its metals." This is certainly true, but of late a good deal has been done to remedy this defect, especially by the publication of the valuable series of Special Reports of the Geological Survey on the Mineral Resources of Great Britain. We are glad to note that the Secretary for Mines went on to state that arrangements had been made for co-operation between his department and the Geological Survey in this matter. From this much good should arise.

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Professor W. G. Fearnsides, of Sheffield University, has gone to Canada and the United States on a year's leave in order to study geological conditions in those countries. In his absence the geological department at Sheffield will be in charge of Mr. W. H. Wilcockson, Lecturer in Geology.

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Dr. Arthur Holmes, formerly Assistant Demonstrator in Geology at the Imperial College of Science and Technology, has lately returned to Burma, after a trip home on leave. He will in future reside at Yenangyaung in order to manage the oil and coal fields of the Yomah Oil Company. We understand that Dr. L. Dudley Stamp will shortly proceed to Burma to undertake geological work under the same company.

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Dr. Stanley Smith recently sailed for Canada to take up the duties of Assistant Professor of Geology at Queen's University, Kingston, Ontario.

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The 89th meeting of the British Association for the Advancement of Science, held at Edinburgh from 7th to 13th September, did not present any features of outstanding interest to geologists. The President of the Association, Sir T. E. Thorpe, devoted part of his inaugural address to an account of the organization and work of the Council of Scientific and Industrial Research, the latest body to assume control of the Geological Survey. On another page we give a list of the papers read in Section C (Geology). Besides these papers

there were joint discussions with other sections on the Mid-Scotland Canal, the Oldest Land Flora, and that well-worn subject, the Age of the Earth. We are not aware that any new geological evidence has recently come to light bearing on this question, which has been abundantly discussed in recent years by Professor Sollas and others.

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Dr. J. S. Flett, F.R.S., President of Section C, devoted his address to the fascinating subject of Experimental Geology, with special reference to the work of Sir James Hall of Dunglass, and its bearing on modern research. We greatly regret that we are unable to afford space to reprint this address in full in the Magazine. It should be read by all petrologists, to whom it will afford much food for thought. We feel sure that few geologists of the present day are acquainted with the wonderful work carried out by Hall a century ago in the investigation of the behaviour of rocks and minerals at high temperatures, and we must be grateful to Dr. Flett for his appreciative sketch of this great Scotsman and great geologist.

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The excursion of the Geologists' Association to Belgium from 20th August to 3rd September was attended with much success. The general direction of the excursion was in the competent hands of Dr. L. Dudley Stamp, and the domestic arrangements were excellently and efficiently managed by Miss M. S. Johnston, Mr. R. S. Herries, and Mr. W. Wright. Consequently everything went off without a hitch, in spite of the difficulty of securing accommodation for a party of nearly fifty in remote places. The following gentlemen most kindly conducted excursions to the localities which they have made their special study: M. A. Renier, M. F. Halet, and Dr. E. Asselberghs, of the Geological Survey of Belgium; Professor J. Cornet, of the School of Mines, Mons; M. Eug. Mailleux, of the Musée Royale d'Histoire Naturelle, Brussels; the Abbé G. Delépine of the Catholic University of Lille, Dr. P. Pruvost, and M. Kaisin. The party stayed at Brussels, Mons, Nismes (for the Couvin district), and Namur, and visited numerous sections in the Devonian, Carboniferous, Cretaceous, and Tertiary rocks, as well as obtaining a glimpse of the Silurians of the Brabant massif and inspecting the vast porphyry quarries at Quenast, the source of so much of the horrible *pavé* of Belgian roads. Professor Dollo also kindly showed the party over the geological department of the Musée Royale at Brussels, and gave a most interesting description of the wonderful collection of reptilian remains, while on the same occasion M. Rutot explained the collection of flint implements. The organizers of this excursion are to be heartily congratulated on the success that attended their labours, which must have been of the most arduous nature.

ORIGINAL ARTICLES.

Silica Percentages of Igneous Rocks.

By V. A. Eyles, B.Sc., and J. B. Simpson, B.Sc. (Agri), B.Sc.

Introduction.

Figs. I-VII give a graphic representation of the average silica percentage of a number of igneous rock types, so arranged as to show the relation between silica-percentage and rock-nomenclature. All the analyses used were obtained from the 1917 edition of H. S. Washington's *Chemical Analyses of Igneous Rocks*".[1] This book contains some 8,000 rock analyses from many parts of the world. They are divided into two classes, superior and inferior. Only those of the former category (some 6,000 in all) have been utilized.

We should at the outset like to make ourselves clear on two points:

(1) The scope of our paper is limited by the acknowledged fact that the nomenclature of igneous rocks depends on many factors in addition to silica percentage.

(2) Our graphs are intended to show what has actually been the practice in the past, rather than to supply a definite ruling for the future.

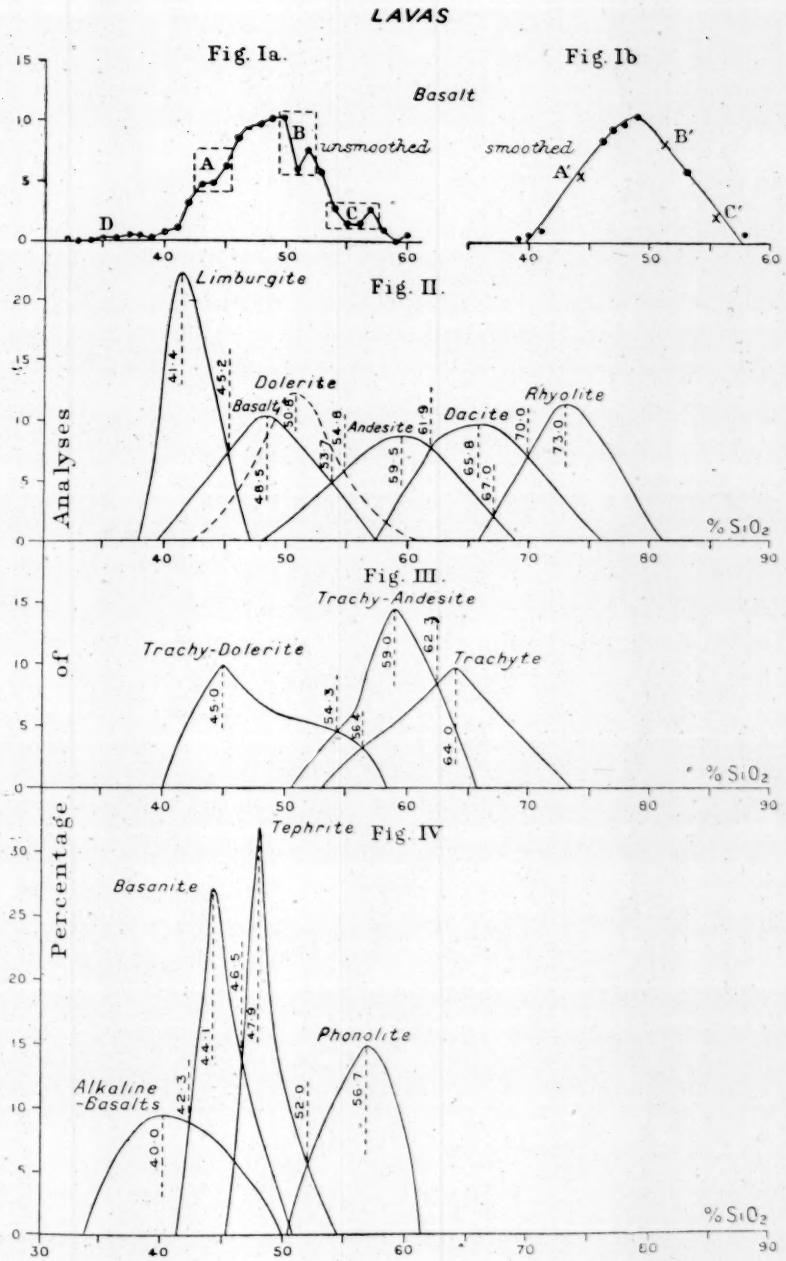
We hope, however, that in view of the general habit of classifying igneous rocks broadly into three groups—acid, intermediate, and basic—our results may have general interest and suggestiveness.

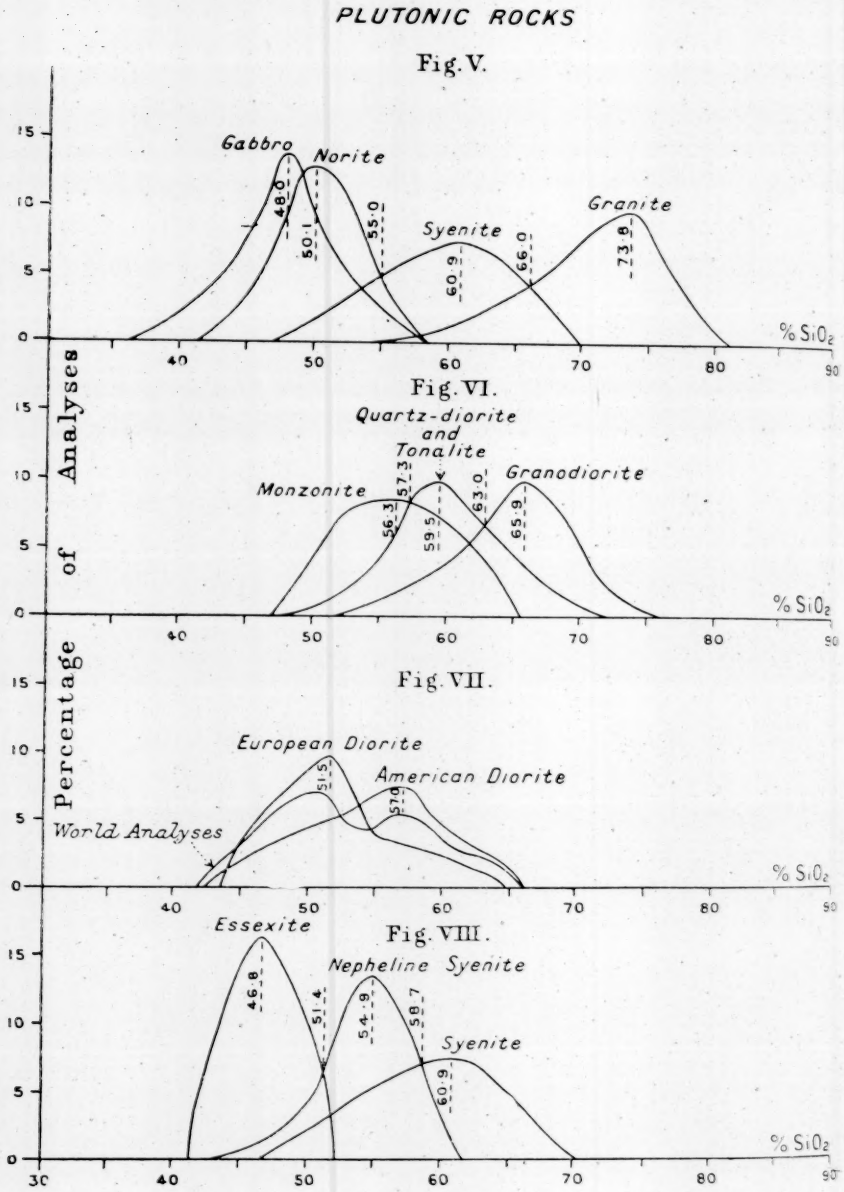
Construction of Curves.

The method of construction of the curves may best be explained by reference to a typical example, such as that for basalt (Figs. I*a*, I*b*). Consider first Fig. I*a*. One finds there a record of the fact that while $8\frac{1}{2}$ per cent of analysed basalts have 46 per cent of silica (reckoned to the nearest whole number), $9\frac{1}{3}$ per cent of them have 47 per cent of silica, and so on. It was found that the available evidence plotted in this fashion gives somewhat inconveniently uneven curves. Accordingly "smooth curves" have been derived by calculating mean points at the chief irregularities in the rough curves. Thus groups of points A, B, C, in Fig. I*a* become points A^1, B^1, C^1 in Fig. I*b*. In addition to this, low-lying flat parts of curves, such as that which occurs under D in Fig. I*a*, have been eliminated, since they obviously lie outside the extreme limits of the species considered.

The following table explains exactly the data used in constructing each curve, stating, for instance, the number of analyses employed. Hypabyssal rocks, with the exception of dolerites, have not been treated, owing to the present relatively undeveloped state of their classification and nomenclature.

[1] Prof. Paper 99, U.S. Geol. Survey.


LAVAS
Fig. Ia.
Fig. Ib
Basalt
A
B
C
D
unsmoothed
smoothed
A'
B'
C'
Fig. II.
Limburgite
Dolerite
Basalt
Andesite
Dacite
Rhyolite
41·4
45·2
48·5
50·6
53·7
54·8
59·5
61·9
65·8
67·0
70·0
73·0
Analyses
% SiO2
Fig. III.
Trachy-Andesite
Trachy-Dolerite
Trachyte
45·0
54·3
56·2
59·0
62·3
64·0
of
% SiO2
Fig. IV
Tephrite
Basanite
Phonolite
Alkaline -Basalts
40·0
42·3
44·1
46·5
47·9
52·0
56·7
Percentage
% SiO2


PLUTONIC ROCKS
Fig. V.
Gabbro
Norite
Syenite
Granite
48.0
50.1
55.0
60.9
66.0
73.8
% SiO2
Fig. VI.
Quartz-diorite and Tonalite
Monzonite
Granodiorite
56.3
57.3
59.5
63.0
65.9
Percentage of Analyses
Fig. VII.
European Diorite
American Diorite
World Analyses
51.5
57.0
Fig. VIII.
Essexite
Nepheline Syenite
Syenite
46.8
51.4
54.9
58.7
60.9

TABULAR STATEMENT ACCOMPANYING FIGS. I–VII.

Rock Name.	No. of analyses.	Arithmetic mean SiO_2 %	SiO_2 % at curve at ex.	Remarks.
Limburgite .	41	42·2	41·4	
Basalt . . .	453	48·4	48·5	*Includes*: Basalts; Olivine-, Quartz-, and Orthoclase-Basalts; Olivine-free Basalts, Basaltic Glass, Scoria, Palagonite and Tachylyte. *Excludes*: "Alkaline" Basalts (see below); Hornblende and Mica-Basalts; Labradorites, Variolites, and Andesite-Basalts.
Dolerite . .	163	51·3	50·8	*Includes*: Diabase and Dolerite. *Excludes*: Altered Diabase.
Andesite . .	455	59·5	59·5	
Dacite . . .	131	65·5	65·8	
Rhyolite . .	275	72·6	73·0	*Includes*: Rhyolites, Liparites, and a few Acid Pantellerites.
Trachydolerite	50	48·4	45·0	
Trachyandesite	27	59·1	59·0	
Trachyte . . .	163	62·5	64·0	*Includes*: Trachytes; Quartz-, Soda-, Calcite-Trachytes; Trachytic Pumice, Bombs, Obsidian, and Pitchstone.
"Alkaline" Basalt	100	40·9	40·0	*Incl des*: Hauyne-, Nosean-, Leucite-, Nepheline-, Analcite-, Melilite-Basalts. *Excludes*: Tephrites; Basanites; Nephelinite; Leucitite; Hauynophyre; Cecilite.
Basanite . .	29	45·4	44·1	
Tephrite . .	47	48·3	47·9	
Phonolite . .	88	56·5	56·7	
Gabbro . .	202	48·6	48·0	*Includes*: Gabbros; Quartz-, Orthoclase-, Micro-, and Essexitic-Gabbros. *Excludes*: Gabbro-Norite, Diorite-Gabbro; Gabbro-Diorite, Enstatite-, Bronzite-, and Hypersthene-Gabbros.
Norite . . .	65	50·1	50·1	*Includes*: Norites; Gabbro-Norites; Enstatite-, Bronzite-, and Hypersthene-Gabbros.
Syenite . .	98	58·6	60·9	*Excludes*: Nepheline-Syenites.
Granite . .	643	71·2	73·8	*Includes*: Granites; Granitites; Adamellites; Microgranites; Granophyres; Graphic Granites; Rapakivi Granites; Alaskite-Granites; Paisanites; Charnockites. *Excludes*: Granodiorites.
All Diorites .	142	52·9	—	*Excludes*: Quartz-Diorite; Tonalite; Gabbro-Diorite; Diorite-Gabbro.
"European" Diorites	53	—	51·5	
"American" do.	83	—	57·0	
Monzonite . .	50	56·3	56·3	
Quartz-Diorite and Tonalite	98	60·3	59·5	
Grano-Diorite .	52	64·5	65·9	
Essexite . .	44	47·1	46·8	*Excludes*: Essexite-Gabbros, -Dolerites, -Lavas, -Diabases, and -Porphyrites; Diorite-Essexites.
Nepheline Syenite	116	56·2	54·9	*Includes*: Foyaite; Litchfieldite; Ditroite; Laurdalite; Sodalite-; and Leucite-Syenite.

The number of analyses taken for each individual type is, we believe, in most cases larger than has hitherto been used in discussions of this nature. It will be seen that the value given by the apex of each curve varies slightly from the average silica percentage. We suggest the former value as more appropriate, since rocks obviously wrongly named have been eliminated in making the smooth curves.

Discussion of the Curves.

A few points of interest are evident in the graphs.

The considerable lateral range of a curve may indicate either looseness in naming, or lack of definition as regards silica-percentage.

The absence of sharp demarcation between types, which we find in nature, is well brought out. The overlapping of the curves is largely due to the influence of those factors, other than silica-percentage, which enter into the present system of classification. The relative basicity of the felspathoid branch of the igneous rocks is well shown.

The diorite curve, plotted on the basis of all recorded analyses, has two well-marked apices, the one at 51, the other at 57. As this feature is too pronounced to be smoothed over, a closer examination of the data has been made. It is found, on considering separately such analyses of diorites as are recorded in European and American publications respectively, that these give two totally distinct curves (Fig. VII). It will be seen that the "European" curve is much the more basic of the two. In fact, in Europe, diorite, as opposed to quartz-diorite, generally means a basic, rather than an intermediate, rock. This is all the more remarkable since rocks named diorite-gabbros and gabbro-diorites have been excluded in the drawing of the curves. Even taking all the diorites together it is clear that their mean silica-percentage is markedly lower than what is usually given as typical for a diorite analysis.

It is not our intention to dogmatize on the curves, however, but to make them available to those who may be interested in particular points.

In conclusion we would like to thank our colleague, Mr. E. B. Bailey, for his help and advice in this compilation.

The Wackerfield Dyke, County Durham.

By Arthur Holmes, A.R.C.S., D.Sc., F.G.S., & Stanley Smith, M.A., D.Sc., F.G.S.

(With analysis by H. F. Harwood, M.Sc., Ph.D.)

(PLATE VIII.)

THE dyke to be described in this paper has not hitherto been noticed in petrological literature, although the western part has been recorded on the map of the area by the Geological Survey. It exhibits, nevertheless, some interesting features and adds data to our knowledge of the minor intrusions of north-east England.

The field investigation has been carried out by one of us [S.S.] and the petrological study by the other [A.H.], and a very complete analysis of the rock has been contributed by Dr. H. F. Harwood.

Field Relations: Situation: 1 inch Geological Map 102 S.W. (New Series Sheet 32), 6 inch map Durham Quarter Sheets 47 N.E. and 48 N.W. Latitude (approx.) 54° 36′; longitude 1° 45′–1° 46′.

The dyke runs E.N.E.–W.S.W. and can be followed for 1,700 yards, from an old quarry a quarter of a mile north-east of Wackerfield (a hamlet 2 miles north-east of Staindrop) to the edge of Trunnelmire Plantation. It outcrops on the divide between the Tees and the Gaunless, a tributary of the Wear, and itself forms the axis of a ridge.

Description of Outcrop.—The dyke has been exposed by quarrying at four places, and it will be convenient to give a brief description of each of these with a view to outlining the general habit of the intrusion. We have indicated these exposures on the sketch-map of the dyke (Fig. 1) by Roman numerals, and have utilized Arabic figures to serve as further points of reference. These Arabic figures also denote the places from which rock specimens were collected.

Exposure I.—The most westerly exposure is an old quarry near the road; this is the best and at the same time the most interesting exposure along the line of the dyke, despite the fact that the old workings are now much obscured by debris and are overgrown by vegetation. The total length of the excavation is about 150 yards, but this includes both a whinstone and a sandstone quarry separated by a thin partition of unworked rock. The dyke runs along the south side of the two quarries and is here very narrow, at the point 2 where both "cheeks" were exposed by hammering its width was rather less than 8 yards. It spreads laterally, however, to form a sill to the north. The limits of the sill cannot be proved; the apophysis extends along the dyke for at least 60 yards, and is exposed about the same distance to the north of it (point 5). The surface features indicate an extension of the sill for some yards north and west of the quarries, but neither the dyke nor the sill have been proved west of the actual whinstone excavations. With fissile sandstone overlying it the sill is well exposed on the east side of the whinstone quarry, indicated at 3 in the remnant of unworked stone that divides it from the sandstone workings. This face of rock runs almost at right angles to the dyke. The upper surface of the sill as seen in this face is practically horizontal and fairly regular, but it rises to the west and reaches the surface of the ground within a few yards.

Although very little solid rock could be laid bare in the shallow workings between the exposure described and a deep excavation in sandstone at the point marked 4, such rock as could be exposed was wholly sandstone. The north cheek of the dyke was proved in the south side of this deep excavation, and the eastern limit of the

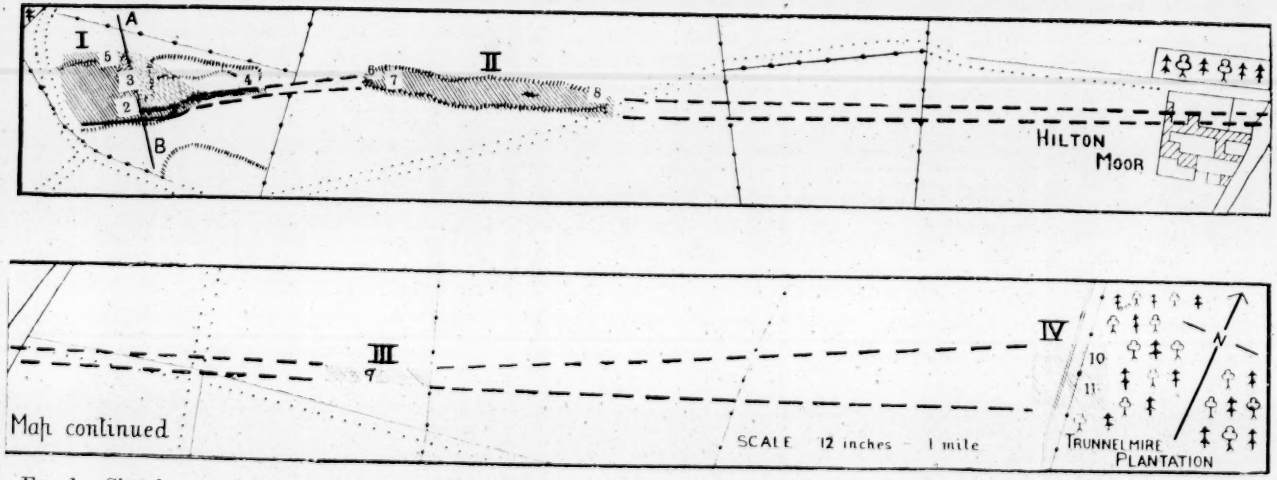


FIG. 1.—Sketch-map of Wackerfield Dyke. Shaded areas represent exposures of the dolerite (broken lines dolerite covered by sandstone). A line bordering shaded areas indicates that the margin of the dyke was there traceable whereas absence of these lines implies the margins were not exposed. A–B indicates line of section (Fig. 2).

sill must therefore closely approximate in position and form with the line we have drawn. The thickness of the sill could not be ascertained as the lower surface is nowhere exposed: the deepest workings are filled with water, but a penetration into whinstone for at least 10 feet is certain.

The rock from the dyke and from the upper part of the sill was much decomposed, particularly so in the latter case; in contact with the overlying sandstone and for a foot or more down it has been changed to a friable ochreous material easily mistakable at first sight for ferruginous sandstone.

Exposure II.—The second exposure is found in a deeper quarry in an adjacent field, less than 100 yards N.E. from the first. The rock is almost completely hidden by debris and soil and consequently the cutting now gives very little information beyond fixing the direction of the dyke and indicating an approximate width. In Exposure I the dyke was striking nearly N.E.–S.W., in this it is running E.N.E.–W.S.W., a direction it continues to follow along the rest of its proved course. The estimated width must closely approach 30 yards. What little rock was actually exposed was wholly dolerite, and this included some remarkably fresh material (6). The freshest samples were obtained near the surface immediately beneath a thin covering of drift.

FIG. 2.—Section along A–B (FIG. 1), drawn from southern margin of dyke to middle of face "3".

Exposure III.—This quarry, 250 yards east of Hilton Moor Farm, was "opened out" within recent years, but has since been filled in again. Only a trench-like depression in the ground now marks the position and trend of the dyke, and affords data for a rough estimation of its width, which is evidently about 15 yards. No rock *in situ* can now be seen.

Exposure IV.—The intrusion forms a well-marked feature where it enters Trunnelmire Plantation, but this can only be followed a short distance into the wood. Three or four small trials made just within the plantation have exposed the rock; this is remarkably fresh. The dolerite forms here an outcrop at least 50 yards in width, and unless the dyke is abnormally wide at this point another sill is indicated.

To summarize the information yielded by these exposures: The dyke can be traced for nearly a mile, and with the exception of a deflection near the western end it runs in a straight line; on the other hand it varies considerably in width, and is dilated at both

ends. Continuation beyond the limits shown on the map cannot be proved, and that it persists at the surface is unlikely. At the terminations the intrusion is responsible for marked surface features, but throughout the rest of its course it merely constitutes the backbone of a ridge which is but one of a series with a common trend. The western feature forms the crest of the divide between the rivers before mentioned—the Tees and the Gaunless—but the eastern one lies within the drainage of the latter stream.

The Cleveland and Hett Dykes.

Before proceeding to discuss the petrological characters of the intrusion and the wider problems which then arise, some brief notice must be taken of the other two dykes which traverse the region, namely, the Cleveland and Hett Dykes.

It will be seen from the map of the area (Fig. 3) that the Wackerfield Dyke, if it persisted only another 500 yards, would cross the path of the Cleveland Dyke, but the latter appears to be absent at the surface between the Bolam and Buck Head laccoliths. There are no surface indications of the Cleveland Dyke between the laccoliths and, moreover, colliery workings have crossed the line of the dyke without encountering the intrusion.

It would be out of place to discuss here, except in bare outline, the habits of this great dyke and the character of its apophyses, particularly as we hope at some future date to deal with the intrusion in detail, but the following facts may be stated. The dyke runs in an E.S.E.–W.N.W. direction from the vicinity of Whitby to the neighbourhood of Carlisle, but it is not persistently present at the surface throughout its long course. East of the Bolam sector, which terminates a mile and a half east of our map, it has not been proved within 14 miles; where next seen it is traversing Triassic beds at Coatham Stob, 3½ miles S.W. of Stockton. Within the neighbourhood with which the present paper is concerned it spreads out into a number of sills and laccoliths; the laccolith north of Bolam village is by far the largest of these. Igneous rock has been injected between the strata on both sides of the dyke along a length of some 1,200 yards. Although the laccolith attains its greatest thickness on the south side of the dyke, its lateral extension is greatest on the north. The igneous sheet is concealed to a very large extent by sandstone and the boundary we have mapped can be merely conjectural. The igneous rock, overlain by sandstone, has been exposed in a small quarry marked "*a*", nearly 400 yards away from the dyke, and further east a little distance beyond the limits of our map there are traces of whinstone workings 1,200 yards north of the dyke. The stone wrought in the old quarry in question may have been part of the laccolith, or may indicate a branch from the main dyke, the interpretation of the Geological Survey. We have as yet insufficient data to justify any decision.

At Buck Head the injection is wholly on the south side of the

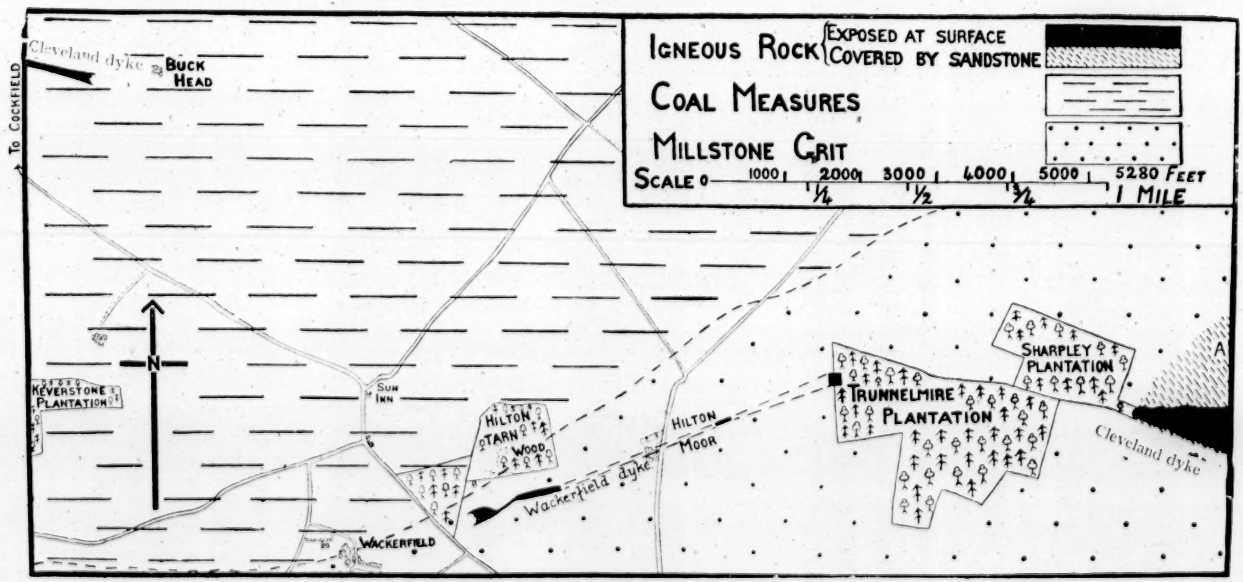


FIG. 3.—Map of country north of Wackerfield

dyke. The laccolith has considerable thickness but is not extensive; it has to some extent the characters of a cedar-tree laccolith. Attenuation of the dyke takes place in proximity to horizontal injection in all cases.

These statements show that the Wackerfield Dyke outcrops on the south side of the more important intrusion but coincides in its extent with a gap in the surface continuity of the great dyke and that both dykes give rise to horizontal offshoots in the same region and in the same manner.

The two dykes are petrologically quite dissimilar and can have no direct genetic relationship. Without anticipating unnecessarily the subsequent section of this paper it may be stated that the Cleveland Dyke has an andesitic character and is of Tertiary Age, whilst the Wackerfield Dyke is a dolerite mineralogically identical with the Whin Sill but of a finer texture. It also resembles the Hett Dyke both in texture and composition, but perhaps less closely so than it does the Whin Sill. Consanguinity between these dykes and the Whin Sill may fairly be assumed and a Carboniferous age argued.

The Hett Dyke, which has the same E.N.E.–W.S.W. bearing as the Wackerfield Dyke, has been traced from the vicinity of Durham to that of Middleton-in-Teesdale, some 25 miles, and has been quarried at many points and for considerable lengths along its course. It is a narrow dyke—at Howden le Wear, where it was followed by one of us for some 2 miles, it only varied in its width from 12 to 18 feet—but runs in a remarkably straight line across the country it traverses.

Petrology.

Megascopic.—The fresh rock of the Wackerfield Dyke is remarkably uniform in appearance throughout the different exposures. It is a dark-grey finely crystalline rock which closely resembles the most commonly occurring variety of the Whin Sill, but the texture becomes somewhat finer near the margins of the intrusion. The rock is altered in places to a buff-coloured material, and between this and the typically fresh rock are intervening stages in which the colours are dull green, purple, and tints of grey. This alteration, although affecting more particularly their contacts, penetrates deeply and irregularly into the dyke and sills. The nature of the alteration is discussed later, and for the present only the fresh rock will be considered. Some dozen specimens were collected for study, and all show an even-grained texture practically free from phenocrysts. Careful examination with a lens reveals a few sparsely distributed phenocrysts of felspar, the longest dimension being about three millimetres, against an average for the bulk of the rock of 0·8 millimetre. The specific gravity varies from 2·90 to 2·98, the actual values for particular specimens being as follows :—

No. 1	6	8	9	10	11
2·96	2·96	2·93	2·97	2·90	2·98

Microscopic.—Under the microscope all the fresh rocks have precisely similar characters, the only detectable variation being in the quantitative proportions of the constituents. The minerals may be considered in four groups: plagioclase, pyroxenes, black ores, and interstitial material. No glass is present, but the interstitial material, which appears to be mainly quartz, occupies many of the wedged-shaped spaces between the essential constituents, and the dominant texture may therefore be described as intersertal. Ophitic relations are also developed in places, though not conspicuously. The characteristic appearance seen in thin section is illustrated by Fig. 1 of Pl. VIII.

Plagioclase.—As in the Whin Sill plagioclase is the most abundant constituent. Except in the marginal facies of the rocks it is perfectly fresh, generally free from inclusions and of prismatic habit, giving lath-shaped and nearly square sections. The smaller prisms are of uniform composition, but larger crystals of the same habit show zoning, while the rare phenocrysts are again uniform but markedly calcic in composition. The smaller prisms constitute the dominant type, and the extinction angles, average refractive index, and specific gravity indicate that its composition is not far from Ab_{40} An_{60}. The larger prisms are richer in anorthite in the core, which is often well marked, but the outer layers vary rapidly from labradorite to oligoclase, the peripheral parts having practically the same refractive index as Canada balsam. The range is thus from about Ab_{30} An_{70} to nearly Ab_{90} An_{10}. The rare phenocrysts all show irregularly rounded forms suggesting resorption of the original peripheral portions. The internal parts approach anorthite in composition (about Ab_{10} An_{90}), and there is little change towards the corroded rim. Irregular streaky inclusions are present as in the larger felspars of the Whin Sill and the corroded and dislocated felspar aggregates of the Crookdene and Collywell dykes of Northumberland.[1] Viewed under a high-power objective, the inclusions are found to consist of pyroxene, felspar, and black ores, suggesting that they were originally blebs of magma which afterwards consolidated inside the felspars which caught them up.

Miss Heslop and Dr. Smythe suggest that the anorthite aggregates of the Crookdene and Collywell dykes were formed in depth and that they floated up through the magma and thus tended to become concentrated near the head of the dykes, where, in fact, they are found. Viewed in this light, the observations point to the present exposure of the Morpeth Dyke having been the lowest, that is, the farthest removed from the head of the dyke at the time of consolidation; next, in ascending order, comes the Tynemouth Dyke, and, lastly, the dykes of Collywell and Crookdene."[2] Although the Wackerfield dyke differs in certain respects from those investigated by Miss Heslop and Dr. Smythe, it appears likely that the

[1] M. K. Heslop & J. A. Smythe, *Q.J.G.S.*, vol. lxvi, 1910, p. 7.
[2] Ibid., p. 17.

felspar-phenocrysts or enclosures (as they probably are) have had a similar origin and history. Their composition, which is abnormal, and the resorption of their outer parts, show that the crystals were not in equilibrium with the material by which they are now surrounded. They must, therefore, have sunk down or floated up, and both specific gravity evidence and the probabilities of the case point to the latter process as the more probable alternative.

Pyroxenes.—Both orthorhombic and monoclinic pyroxenes are present. Each is of a pale grey-green tint, but there is little difficulty in distinguishing the two species. The orthorhombic pyroxene is only slightly pleochroic, and its composition approaches enstatite rather than hypersthene. It builds stout prismatic crystals of hypidiomorphic outlines, and sometimes occurs as nucleus-crystals, around which aggregates of the monoclinic pyroxenes have grown. The latter are far more abundant than the enstatite and their small optic axial angle indicate that they are not diopside or augite but enstatite-augite. The existence of a series of mixed crystals between clino-enstatite and diopside is now well established, and natural aluminous representatives have been recognized as the characteristic pyroxene of many doleritic rocks. Already in 1884 Sir Jethro Teall, in his masterly study of the Whin Sill, showed by analysis that the monoclinic pyroxene contained approximately nineteen molecules of diopside-hedenbergite to ten of enstatite, with smaller amounts of alumina and ferric oxide. The same type of pyroxene is present in the Wackerfield dyke, and the similarity extends to the mode of occurrence, which is in small grains or larger irregular plates, and to the presence of a fine striation which characterizes certain parts of the larger plates. The colour is grey-green rather than pale brown, but brownish patches occur sporadically suggesting local concentration of iron, and possibly titanium, oxides.

The alteration-products of the two pyroxenes are worthy of attention. The monoclinic pyroxene is sometimes altered to fibrous green actinolite, especially around the borders. The orthorhombic pyroxene, however, tends to be more deeply altered, but only when it occurs as isolated crystals. The alteration-product is a brown fibrous mineral showing strong pleochroism, and giving invariably straight extinction. The birefringence is about 0·020, and it seems clear, therefore, that the mineral is anthophyllite.

Black Ores.—The opaque constituents consist entirely of titaniferous magnetite. From the crushed rock practically the whole of the mineral is abstracted by a bar magnet, and the small second crop obtained by the electro-magnet consists of grains which are largely felspar or augite. In thin section the titaniferous magnetite builds skeletal crystals and also occurs in irregular masses of very different sizes. It encloses both pyroxene and felspar ophitically and is evidently of comparatively late crystallization.

Interstitial Material.—Between the other minerals, the interstitial spaces, sometimes larger than the average grain-size of the rock, but

generally much smaller and of wedge-like shape, are occupied by a fine granular aggregate, which appears to be mainly quartz. However, it is not wholly quartz, as the material has a pale-green colour, and examination under high power reveals the presence of a fibrous green chloritic mineral and of occasional minute flakes of sericite and rare blebs of a carbonate mineral. In other parts of the rock irregular spaces are occupied mainly by cloudy aggregates of calcite. No true amygdales occur, but it seems likely that the infilling of the final residual spaces represents a late magmatic stage of consolidation corresponding to that which fills the amygdales of the Whin Sill and the Hett dyke. The effects of this stage of the cooling history are seen most conspicuously in the altered peripheral portions of the intrusion.

Other Minerals.—Careful search through a series of thin sections revealed no additional minerals except a clear needle-like crystal of apatite associated with the calcite aggregates. No mica or pyrite has been detected in the fresh rock.

Mineral Analysis.—A series of micrometric analyses by the Delesse-Rosiwal method gave the following percentages by volume. Results for a specimen of the Hett dyke and for two specimens of the Whin Sill are added for comparison.

Minerals.		*Wackerfield Dyke.*			*Hett Dyke.*[1]	*Whin Sill.*[2]	*Whin Sill.*[3]
		No. 1.	*No.* 6.	*No.* 11.			
Felspars		55·6	54·0	52·7	52·3	53·7	48·9
Pyroxenes		34·5	30·2	31·8	30·8	33·1	39·8
Black Ores		5·2	6·6	7·2	6·8	5·8	7·2
Interstitial		4·7	9·2	8·3	10·1	7·4	4·1
Spec. Grav.	Calculated	2·96	2·98	3·01	2·98	2·98	3·04
	Determined	2·96	2·96	2·98	2·95	2·94	3·01

The calculated percentages by weight are set forth below, together with the specific gravities (approximate only), used for the groups of minerals measured.

Minerals.	*Spec. Grav.*	*Wackerfield Average.*		*Hett Dyke.*	*Whin Sill.*	*Whin Sill.*
		Volume.	*Weight.*			
Felspars	2·7	54·1	49·0	47·4	48·7	43·4
Pyroxenes	3·2	32·2	34·5	33·0	38·6	41·8
Black Ores	4·8	6·3	10·1	10·8	9·3	11·3
Interstitial	2·6	7·4	6·4	8·8	6·4	3·5

[1] Lunedale, Yorkshire.
[2] Kirkwhelpington, Northumberland.
[3] Greenhead, Northumberland.

These results reveal a remarkable similarity between the rocks investigated, and even though they cannot be considered as strictly accurate, they suggest in a general way a correlative feature to which attention was first directed in a recent paper by one of us (A.H.) on "The Basaltic Rocks of the Arctic Region".[1] It was there shown that in the over-saturated basalts of Iceland and the Faroes the black ores decreased as the felspars increased, and the same kind of relation, though with a different correlative factor, was found to hold among the olivine-basalts of Iceland. As soon as chemical analyses became available, it was found that the antipathy could be best expressed by comparing titanium dioxide with normative plagioclase, and that a simple relation existed between these constituents which held for nearly all the analysed olivine-free basaltic rocks from Siberia in the north-east to Greenland on the north-west and Mull in the south. The exceptions were found to be somewhat abnormal in texture and composition, as they all contained numerous glomero-porphyritic aggregates of bytownite.

A suggestion of a similar antipathetic relation between felspars and ores is detectable in the results here presented, as shown by the weight-percentages :—

Felspars .	43·4	47·4	49·0	48·7
Black Ores .	11·3	10·8	10·1	9·3

Tested by the available analyses, which unfortunately are few at present, and in the case of the Hett dyke, too poor to be of service, the significant antipathetic variation of titanium dioxide and normative plagioclase is found to hold. And not only so, but the correlative factor approximates so closely to that of the Brito-Arctic unsaturated basaltic rocks that the figures fit into the series with only a very slight discrepancy.

Locality.	*Titanium Dioxide.*	*Normative Plagioclase.*
Spitzbergen . .	2·93	42·56
Mull	2·80	42·42
Whin Sill (B) . .	*2·42*	*44·83*
Franz Josef Land .	2·29	46·63
Wackerfield (A) . .	*2·22*	*45·36*
Whin Sill (C) . .	*1·92*	*47·21*
Kuzkin Island . .	1·63	51·30
Mull	1·46	59·36
Mull	1·46	61·83
Mull	0·93	66·16

We hope in a later paper to present analyses by means of which the suggested relation may be tested more rigorously. There can be no doubt that the Brito-Arctic Tertiary rocks are derivates from a regional magma or series of magmas of uniform composition, in which some continuous process of differentiation has brought about the remarkable relation which has been disclosed. It seems probable that by the sinking of olivine crystals a separation of under-

[1] *Min. Mag.*, vol. xviii, 1918, p. 216.

saturated from oversaturated material became possible. Within each type of magma the crystallization and slight upward concentration of plagioclase (lighter than the magma), accompanied and followed by a slight downward concentration of the heavier black ores, would then take place. Such a process, being continuous in depth, but arrested locally by intrusion or eruption, would appear to explain the antipathy between the constituents mentioned. It is suggested that the Wackerfield dyke, the Hett dyke, and the Whin Sill are related by some such community of process, and that they were drawn either from a single uniform magma or from a series of uniform magmas.

Moreover, chemical, mineral, and textural evidence shows not only that the parent magma was similar to that from which the oversaturated Brito-Arctic basalts were derived, but that the processes which acted on each were in all essentials identical. This conclusion does not warrant the deduction that the Whin Sill and the related dykes are of Tertiary age, for that would imply that similar processes acting on similar materials could take place only during a single period of the earth's history. On the contrary, many features of late Carboniferous magmatic history are known to have been repeated in the igneous episodes of the Tertiary, and correlation of process between certain Tertiary rocks and the Whin Sill group must therefore not be confused with correlation in time.

Chemical Composition.—We are indebted to Dr. H. F. Harwood for the following excellent analysis of specimen No. 6 :—

Constituents.	*Percentages.*	*Molecular Proportions.*	*Norm.*	
SiO_2	50·30	838	Quartz	5·22
Al_2O_3	14·11	138		
Fe_2O_3	3·16	20	Orthoclase	4·38
FeO	9·90	138	Albite	19·78
MgO	5·56	139	Anorthite	25·58
CaO	8·54	153		
Na_2O	2·34	38	Diopside	11·40
K_2O	0·74	8	Hypersthene	20·40
H_2O (> 105° C.)	1·94	—		
H_2O (at 105° C.)	1·01	—	Magnetite	4·55
CO_2	0·16	4	Ilmenite	4·22
TiO_2	2·22	28	Apatite	0·61
P_2O_5	0·30	2	Calcite	0·36
MnO	0·12	2		
BaO	0·03	—		97·50
SrO	none found	—	Water	2·95
S	none found	—		
Cl	trace	—	Total	100·45
ZrO_2	trace	—		
Total	100·43		Specific Gravity	= 2·98.

The analysis is recalculated into standard mineral compounds (normative minerals), and restated in this form on the right. The mineralogical characters of the rock are faithfully reflected by the standard mineral composition ; that is to say, the mode is nearly

normative. The normative compositions of plagioclase, pyroxenes, and opaque ore corresponds closely with those revealed by microscopic examination.

The analysis as a whole is that of a typical oversaturated dolerite, and for comparison and contrast it is repeated below, together with analyses of the Whin Sill, of a dyke and lava-flow occurring in Mull, and of the Cleveland dyke.

	A.	B.	C.	D.	E.	F.
SiO_2	50·30	51·22	50·71	51·63	50·54	57·57
Al_2O_3	14·11	14·06	14·78	11·77	12·86	14·25
Fe_2O_3	3·16	4·32	3·52	3·23	4·13	6·04
FeO	9·90	9·03	8·95	10·52	8·75	3·95
MgO	5·56	4·42	5·90	5·02	4·63	4·24
CaO	8·54	8·33	8·21	9·34	8·74	6·87
Na_2O	2·34	2·55	2·76	2·90	2·42	2·98
K_2O	0·74	1·25	1·39	0·91	1·43	1·08
H_2O+	1·94	1·28	1·78	1·40	2·24	1·25
H_2O-	1·01			0·68	0·21	
CO_2	0·16	0·19	0·25	0·11	0·19	0·30
TiO_2	2·22	2·42	1·92	2·00	2·80	trace
P_2O_5	0·30	0·25	n.d.	0·29	0·26	0·15
MnO	0·12	0·16	0·31	0·35	0·32	0·27
BaO	0·03	n.d.	n.d.	0·03	n.f.	n.d.
S	n.f.	0·26	n.d.	0·04	n.f.	0·19
Totals	100·43	99·74	100·48	100·28	100·12	99·14
Sp. Gr.	2·98	2·98	2·94	—	—	2·77

A.—Wackerfield Dyke. H. F. Harwood, *analyst.*

B.—Whin Sill. Cauldron Snout, Durham. J. J. H. Teall, *analyst. Q.J.G.S.*, xl, 1884, p. 654.

C.—Whin Sill. Crags near Borcovicus, Northumberland. J. J. H. Teall, *analyst. British Petrography*, 1888, p. 209.

D.—Tholeiite of Branton Type. Dyke near Kintallen Mull. E. G. Radley, *analyst. Summ. Prog. Geol. Surv. for* 1914, 1915, p. 55 (Lab. No. 411).

E.—Basaltic lava, Mull. E. G. Radley, *analyst. Summ. Prog. Geol. Surv. for* 1915, 1916, p. 26 (Lab. No. 448).

F.—Cleveland Dyke, Great Aytoa, Yorkshire. W. F. K. Stock, *analyst. British Petrography*, 1888, p. 206.

It will be seen at once from inspection of the first three columns that the composition of the Wackerfield dyke (except in regard to potash) corresponds as closely with that of the Whin Sill as one analysed sample of the Whin Sill does with the other. Chemical evidence, therefore, strongly supports the view of type-identity already recognized by Miss Heslop, and developed here in the preceding paragraphs. The difference in potash is in accordance with the only noteworthy petrographical difference between the Wackerfield dyke and the Whin Sill, namely, the absence of recognizable micropegmatite and biotite from the former. The Hett dyke is petrographically identical with the Wackerfield dyke, but the old analyses which at present are alone available are

incapable of providing a satisfactory basis for chemical comparison. The two analyses of Tertiary rocks from Mull are given to demonstrate the similarity to which reference has already been made.

The Cleveland dyke, like the Whin Sill, is extraordinarily uniform throughout its range, and the uniformity is borne out by a number of fairly good analyses. One of these is quoted in the table above, in order to bring out the fact that it is of andesitic rather than doleritic composition. The Wackerfield dyke evidently belongs to a different suite from that of which the Cleveland dyke is the type. It is possible that between the tholeiite group of the Northumberland dykes, the Whin Sill group, and the Cleveland dyke group there are genetic relations similar to those connecting the tholeiites, cumbraites, leidleites, and inninmorites of the Clyde area.[1] Here, again, differences of geological age have no necessary bearing on the question, but in the absence of sufficient adequate chemical data, discussion of this petrological problem must be deferred.

Alterations.

As already stated, the dyke-rock does not depart from a uniform type except where the minerals have suffered a marked alteration. This alteration is largely but not entirely marginal, and there the rock is slightly—but very slightly—finer in texture.

Microscopic examination indicates that the alterations are of two distinct kinds: one related to silicification and the other to carbonatization.

Specimen No. 7 (taken from floor of quarry and from near the centre of the dyke at a depth of about 20 feet or more—Exposure I) is typical of the latter. The rock is pale grey with occasional splashes of brown limonitic staining. In thin section it is seen that the pyroxenes are replaced by cloudy granular aggregates of carbonate minerals, penetrated in places by numerous acicular crystals of apatite, and associated with sporadic grains of pyrite. Certain vaguely defined rhombs suggest the presence of dolomite in addition to calcite, and this is confirmed by chemical tests. The felspars are slightly fogged, but twinning and zoning still remain. Small flakes of biotite have developed, especially between titaniferous magnetite and the interstitial matter, suggesting an interaction between these minerals promoted by the percolating solutions either during or after their attack on the pyroxenes. The interstitial material as a whole remains unaffected.

Specimen No. 4 (from the north cheek of the dyke immediately east of the sill—Exposure I) is a brownish-green rock with a faintly purple coloration here and there. The dominant alteration is the replacement of the felspars by quartz, chalcedony, and opal. The opal appears in core-like granules and streaks, these, surrounded by chalcedony, give the felspars a mottled relief due to rapid alternations

[1] G. W. Tyrrell, Geol. Mag., 1917, pp. 305 and 359. See also S. Tsuboi, *Journ. Geol. Soc. Tokyo*, xxv, 1918, p. 47.

of low and medium refractive index, which is very characteristic of silicification. Carbonates are almost wholly absent, and neither apatite nor pyrite have been detected. The pyroxenes and also the opaque minerals are largely replaced by brown limonitic material, but cores of the fresh minerals still remain, together with chloritic borders around the pyroxenes and cream-grey streaks of leucoxene traversing the opaque minerals. The interstitial matter, as before, remains unaltered.

Specimen No. 8 (surface of the dyke, near margin—Exposure II) exhibits the effect of weathering on material of the same type as No. 7. Calcite and dolomite have both been leached out almost completely, while limonite has been leached out in certain parts and concentrated in well-marked bands parallel to the exposed surface.

It is clear that the two processes of alteration are of the same character as those involved in the infilling of the amygdales found in the Whin Sill and the Hett dyke. They represent a late-magmatic (paulopost) and probably hydrothemal stage of the waning magmatic activities, and have nothing to do with weathering, as commonly supposed, although at the same time the material in question is deeply weathered.

The alteration to the margins is evidently a consequence of the contraction of the dyke. The residual liquors, wherever situated, would tend to become concentrated and to move upwards along the channels offering least resistance; that is to say, along the contraction fissures which developed along the margins.

EXPLANATION OF PLATE VIII.

Magnification = 22·5 diameters.

FIG.

1.—Typical field of the dolerite of the Wackerfield dyke. Specimen No. 6 from Exposure II. See p. 446 for description.

2.—Typical field of the dolerite of the Little Whin Sill, Stanhope. The minerals are identical with those of the Wackerfield dyke, except that the felspars are slightly turbid. In texture the only difference is that here the felspar laths are less uniformly dispersed.

3.—Corroded phenocryst of bytownite in the Wackerfield dyke. Specimen No. 1 from Exposure I. See p. 447 for description.

The Foraminifera of the Hartwell Clay and Subjacent Beds.

By E. NEAVERSON, M.Sc., F.G.S.

(PLATE IX.)

INTRODUCTION.

DURING a temporary cessation of work on the Ammonites of the Hartwell Clay, the writer was asked to identify a series of Foraminifera found by Mr. E. Hollis of the Bucks. County Museum, Aylesbury, in washing a sample of clay from Hartwell. Other samples were collected and examined from all the available

G. S. Sweeting, photo.

PHOTOMICROGRAPHS.

Magnification = 22·5 diameters.

[To face p. 454.]

exposures of Hartwell Clay, and the results are given below. A series of the Foraminifera has been deposited in the Aylesbury Museum.

Previously the Foraminifera of this interesting deposit had received scant attention. A short list is given in the Geol. Surv. Memoir by H. B. Woodward (*Middle and Upper Oolites*, 1895, p. 227), but on account of the terminology employed, some revision appears necessary. In 1897 F. Chapman recorded fifteen species from Hartwell (*Proc. Geol. Assoc.*, vol. xv, p. 97), remarking that they "present a facies comparable with that of the Neocomian (*sic*) and Gault". No other lists appear to have been published, and the forms have not yet been described.

Foraminifera from beds of approximately the same age have been described by:—

Chapman (Tithonian Foram. Stramberg; *Linn. Soc. Journ. Zool.*, vol. xxviii, 1900, p. 28);

Perner (Ueber Foram. Tithon, Stramberg: *Bull. Acad. Bohême*, 1898, p. 1); and

Haeusler (Die Astrorhiziden und Lituoliden des Bimammatus Zone; *N. Jahrb.*, 1883, vol. i, p. 55).

Other works consulted are indicated in the text, but the synonymy is reduced to a minimum, only a few of the more important references being given.

The writer is indebted to Mr. E. Hollis for help in the collection and preparation of material, to Mr. S. S. Buckman, Mr. C. P. Chatwin, and Dr. A. Morley Davies for kindly criticism and suggestions, to Professor P. G. H. Boswell for reading the manuscript; also to Dr. F. L. Kitchin for an opportunity recently of examining Chapman's specimens of Gault Foraminifera, now in the Museum of Practical Geology. For this assistance the writer wishes to express his gratitude.

Notes on Stratigraphy of the Beds.

A combination of circumstances renders the determination of the zonal sequence in the Hartwell Clay and underlying beds a matter of some difficulty. The number of exposures is limited, some of the brickfields have not been worked for a considerable time, the workings are shallow, and the ammonites usually in a fragmentary condition. The identification of the ammonites also is not yet complete; only a provisional indication of the horizons is therefore given.

The typical Hartwell Clay is exposed at Hartwell, Aylesbury, and Bierton, and contains ammonites usually identified as *Perisphinctes pallasianus* (d'Orb.). This clay is overlain by the Portland Pebble-bed, which has weathered down to a sandy consistency. The clay at Whitchurch (5 miles north of Aylesbury) is probably on the same horizon as that at Hartwell, because, though it differs from the latter in the presence of selenite, fragments of ammonites occur

which seem to be the typical Hartwell forms. The deposit at Long Crendon, near Thame, represents a lower horizon than that usually worked at Hartwell. It contains some of the characteristic Hartwell Clay fossils, but the ammonites present different characters, being large inflated Perisphinctids with fairly coarse ribs. Similar ammonites were found at Hartwell years ago when the workings were deeper. At Wheatley and Shotover Hill the clays contain nodules enclosing ammonites of a still different type—fine-ribbed Perisphinctids involute in youth becoming evolute later; coarse-ribbed species, however, occur at both localities. These clays have until recently been referred to the Kimmeridge Clay, but an examination of the residues has disclosed the presence of glauconite, a mineral which appears to be absent from the typical Kimmeridge Clay of the district.[1] This, and the occurrence of typical Hartwell Clay belemnites in the clay at Wheatley appear to indicate that these beds should be classified with the Hartwell Clay as Bononian.[2] The following is a summary of the beds under discussion :—

4. Typical Hartwell Clay of Hartwell, Aylesbury, Bierton, and Whitchurch.

3. Hartwell Clay of Long Crendon—a lower horizon than that usually worked at Hartwell.

2. Highest "Kimmeridge Clay" of Wheatley and Shotover Hill—a sandy clay.

1. Blue Clay of Wheatley and Shotover Hill with nodule band as basement bed.

General Characters of the Clays and of the Microzoa.

The following notes give the general characters of the microzoa; and also of the sediments from the various localities, pending a complete petrographical description.

Hartwell.—Abundant quartz and glauconite grains occur, many of the latter being casts of Foraminifera; marcasite is common, sometimes filling tests of Foraminifera, more often as spherical concretions. Ostracods[3] are common, and Foraminifera abundant; hooklets from the tentacles of a belemnoid, remains of echinoderms,[4] fish-teeth, otoliths, and scales are also found.

Aylesbury and *Bierton.*—Quartz and glauconite grains are abundant as at Hartwell; spherical concretions of marcasite also are common. Foraminifera and ostracods are common, but the number of species is relatively small.

Whitchurch.—Selenite is the commonest mineral in the residues, occurring often in well-formed crystals. Quartz and glauconite are common, whilst marcasite frequently occurs. Foraminifera

[1] See also A. M. Davies, *Q.J.G.S.*, vol. lxviii, 1907, p. 36.
[2] See A. M. Davies, *Introd. to Palæontology*, 1920, p. 385.
[3] Chapman, *Proc. Geol. Assoc.*, vol. xv, 1897, p. 97 (list of species).
[4] Bather, Geol. Mag., 1916, p. 302.

are relatively rare, probably owing to the abundance of selenite. Ossicles of *Isocrinus* were found here.

Long Crendon.—Abundant quartz and frequent grains of glauconite, but the latter is not so common here as at localities nearer Aylesbury. Ostracods rare. Foraminifera common.

Wheatley and *Shotover Hill.*—Highest "Kimmeridge Clay"—Quartz grains and small aggregates of marcasite are abundant; glauconite grains occur, but are not common. Foraminifera abundant, ostracods common. Blue clay above nodule band. Quartz grains and small concretions of marcasite are the commonest minerals, whilst glauconite is rare. Foraminifera and ostracods are common.

Speaking generally, the colour of the glauconite of the Hartwell Clay is a rich green, but many grains present a dull yellowish appearance. This yellow colour appears to be due to decomposition, as on boiling with dilute hydrochloric acid the grains become green. The size of the grains is variable, some glauconite being present in each grade-size separated by elutriation, but they do not occur in grades greater than 0·5 mm. diameter, which consist entirely of shell fragments. Exact determinations of the specific gravity of the glauconite have not yet been made, but it is certainly variable. While most of the glauconite has a specific gravity less than 2·8, many grains come down with the heavy detrital minerals separated in bromoform. The grains are usually rounded, but some are sub-angular; many are obviously casts of Foraminifera and occasionally broken specimens of *Cristellaria* have been seen to contain an infilling of glauconite.

This indicates that, although some of the glauconite may be detrital, much is indigenous to the deposit. Similar observations have been made on the glauconite in the Gault of Ford, near Aylesbury, mentioned on a later page. In some samples of the Hartwell Clay, marcasite is most abundant, glauconite being rare. The marcasite occurs as spherical concretions or irregular grains, and often as an infilling in tests of Foraminifera. It would seem that in these cases marcasite has been formed instead of glauconite. It is hoped that more detailed work will show whether these two minerals are connected in any way; for the present no generalization can be made.

The Foraminifera.

In the following notes the occurrence of the Foraminifera at the localities mentioned is indicated by letters, thus:—

v.r. = very rare.	1 to 2 specimens	in 1 lb. of clay.
r. = rare	3 to 5 „	
f. = frequent	6 to 10 „	
c. = common	10 to 20 „	
a. = abundant.	above 20 „	

Family LITUOLIDÆ.

SUBFAMILY LITUOLINÆ.

Reophax, Montfort, 1808.

Reophax scorpiurus, Montfort.

Reophax scorpiurus Montfort, 1808 ; *Conchyl. Système*, vol. i, p. 330, 83e genre.
Reophax helvetica Haeusler, 1883 ; *Q.J.G.S.*, vol. xxxix, p. 27, pl. ii, figs. 8–10.
Reophax scorpiurus Sherlock, 1914 ; Geol. Mag., p. 221, pl. xviii, fig. 1.

A few specimens appear to belong to this species, but they are small and ill-developed. *R. scorpiurus* has been recorded from the Swiss Jurassic (Haeusler), the Oolite of Fontoy, Moselle (Terquem), the Gault of Folkestone (Chapman), and the Speeton Clay of Yorkshire (Sherlock). At present it has a world-wide distribution at depths varying from 3 to 3,960 fathoms (Brady).

Localities : Hartwell (v.r.) ; Whitchurch (v.r.) ; Wheatley, bed 2 (r.) ; Shotover Hill, bed 1 (v.r.).

Haplophragmium Reuss, 1860.

Haplophragmium acutidorsatum Hantken.

Haplophragmium acutidorsatum Hantken, 1868 ; *Magyar földt. tarsulat*, B. 4, S. 82, Taf. i, fig. 1.
H. acutidorsatum Chapman, 1892 ; *Journ. Roy. Micr. Soc.*, p. 4, pl. v, fig. 11.

This is probably the form recorded by H. B. Woodward from the Lower Portland of Bucks as *Lituola nautiloidea* Lam.[1] It resembles *H. emaciatum* Brady, which, however, is an evolute form, whilst *H. acutidorsatum* is involute. The latter is known from the Tertiaries of Hungary (Hantken) and the Gault of Folkestone (Chapman). *H. emaciatum* is a shallow-water form occurring in the West Indies (Brady).

Localities : Hartwell (c.) ; Long Crendon (v.r.) ; Wheatley, bed 2 (v.r.).

Haplophragmium æquale (Roemer).

Spirolina æqualis Roemer, 1840 ; *Verst. norddeutsch. Kreidegeb.*, p. 98, pl. xv, fig. 27.
Haplophragmium æquale Reuss, 1862 ; *Sitz. k. Akad. Wiss. Wien*, xlvi, p. 29, pl. i, figs. 1–7.
H. æquale Chapman, 1892 ; *Journ. Roy. Micr. Soc.*, p. 5, pl. vi, figs. 1–3.

One specimen is referred to this species which was first recorded by Roemer from the Chalk of North Germany. It has since been found in the Upper Hils and Speeton Clay of Germany (Reuss) and the Gault of Folkestone (Chapman).

Locality : Long Crendon (v.r.).

Subfamily TROCHAMMININÆ.

Thurammina Brady, 1879.

Thurammina albicans Brady. (Pl. IX, Fig. 11.)

Thurammina albicans Brady, 1879 ; *Q.J. Micr. Soc.*, vol. xix, n.s., p. 27.
T. albicans Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 323, pl. xxxvii, figs. 2–7.
T. albicans Chapman, 1892 ; *Journ. Roy. Micr. Soc.*, p. 7, pl. vi, fig. 9.

[1] *Mem. Geol. Surv.*, M. and U. Oolite, 1895, appendix, p. 400.

A few specimens from Hartwell are referred to this species, which is recorded from Upper Jurassic strata of Switzerland (Haeusler) and the Gault of Folkestone (Chapman). At the present day it lives off the coast of South America, best developed at a depth of 1,900 fathoms (Brady).

Locality : Hartwell (r.).

Thurammina papillata Brady.

Thurammina papillata Brady, 1879 ; *Q.J. Micr. Soc.*, vol. xix, n.s., p. 26, pl. v, figs. 4–8.
T. papillata, Haeusler, 1883 ; *Ann. Mag. Nat. Hist.*, ser. v, vol. xi, p. 262, pl. viii.
T. papillata Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 321, pl. xxxvi, figs. 7–18.

Several specimens from the Hartwell Clay seem to belong to this species rather than to *T. albicans*. Their colour is brown, their shape variable, and the surface bears irregularly disposed perforate papillæ : often two or more chambers are mutually adherent. *T. papillata* is recorded from the Upper Jurassic of Switzerland (Haeusler), and at the present day is a deep-water form with a world-wide distribution (Brady).

Localities : Hartwell (f.) ; Long Crendon (v.r.) ; Shotover Hill, bed 1 (v.r.).

Family TEXTULARIIDÆ.

Subfamily TEXTULARIINÆ.

TRITAXIA Reuss, 1860.

Tritaxia ? variabilis (Brady).

Verneuilina variabilis Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 385, pl. xlvii, figs. 21–24.

Chapman recorded this form from Hartwell in 1897, but the present writer has failed to obtain it.

Family LAGENIDÆ.

Subfamily LAGENINÆ.

LAGENA Walker & Boys, 1784.

Lagena hispida Reuss.

Lagena hispida Reuss, 1858 ; *Zeitschr. d. deutsch. geol. Ges.*, vol. x, p. 434.
L. hispida Reuss, 1862 ; *Sitz. k. Akad. Wiss. Wien*, xlvi, p. 335, pl. vi, figs. 77–79.
L. hispida Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 459, pl. lvii, figs. 1–4, pl. lix, figs. 2, 5.

This species was originally described from the Oligocene Septaria-clay of Pietzpuhl (Reuss), and Chapman records it from the Gault of Folkestone. Ranging from Lias to Recent, it lives at depths varying from 129 to 1,900 fathoms in many parts of the existing seas (Brady).

Localities : Hartwell (f.) ; Bierton (v.r.).

Lagena lævis (Montague).

Vermiculum lævе Montague, 1803 ; *Test. Brit.*, p. 524.
Lagena lævis Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 455, pl. lvi, figs. 7–14, 30.
L. lævis Sherlock, 1914 ; GEOL. MAG., p. 256, pl. xviii, fig. 14.

Lagena clavata (d'Orb.).

Oolina clavata d'Orbigny, 1846 ; *For. Foss. Vien.*, p. 24, pl. i, figs. 2, 3.
Lagena clavata Reuss., 1862 ; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 329, pl. i, figs. 13, 14.
L. clavata Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 456.

Chapman records *Lagena laevis* from the Hartwell Clay. One specimen, now in the Aylesbury Museum, is referred to *L. clavata*, which is probably a variety of *L. laevis*. This, the only specimen found by the present writer, has a fusiform contour and a pointed base. *L. laevis* is one of the commonest of the *Lagenæ*, and has been recorded from the Woolhope beds (Brady). It occurs at the present day in all latitudes and at all depths down to 2,435 fathoms (Brady). *L. clavata* has a similar distribution (Brady).

Locality : Hartwell (v.r.).

Lagena apiculata (Reuss).

Oolina apiculata Reuss, 1862 ; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 319, pl. i, figs. 4–8, 10, 11.
Lagena apiculata Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 453, pl. lvi, figs. 4, 15–18.
L. apiculata Sherlock, 1914 : Geol. Mag., p. 255, pl. xviii, fig. 12.

Ranging from the Lias to the present day, this form is found abundantly at all depths in existing seas (Brady).

Locality : Hartwell (v.r.).

Lagena sulcata (Walker & Jacob).

Serpula sulcata Walker & Jacob, 1798 ; *Adam's Essays*, p. 634, pl. xiv, fig. 5.
Lagena sulcata Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 462, pl. lvii, figs. 23, 26, 33, 34.

Found at the present day in all latitudes at depths down to 2,750 fathoms (Brady), this species is recorded from various strata and occurs as low as Silurian (Brady).

Locality : Hartwell (v.r.).

Subfamily NODOSARIHNÆ.

Nodosaria Lamarck, 1816.

Subgenera *Glandulina* and *Dentalina* d'Orbigny.

Nodosaria (*D.*) *fontannesi* Berthelin.

Dentalina fontannesi Berthelin, 1880 ; *Mém. Soc. géol. France*, ser. III, vol. i, No. 5, p. 42, pl. ii, fig. 14.
N. (*D.*) *fontannesi* Chapman, 1893 ; *Journ. Roy. Micr. Soc.*, p. 593, pl. ix, fig. 15.
N. (*D.*) *fontannesi* Sherlock, 1914 ; Geol. Mag., p. 257, pl. xviii, fig. 7.

This species was originally described from the Gault of France (Berthelin), and has since been found in the Folkestone Gault (Chapman), and the Specton Clay of Yorkshire (Sherlock).

Locality : Hartwell (v.r.).

Nodosaria raphanus (Linn.).

Nautilus raphanus Linné, 1767 ; *Syst. Nat.*, 12th ed., p. 1164, No. 283.
N. raphanus Linné, 1788 ; *Syst. Nat.*, 13th ed., p. 3372, No. 16.
Nodosaria raphanus Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 513, pl. lxiv, figs. 6–10.

This is the most widely distributed species of *Nodosaria* in the Hartwell Clay, occurring at all the localities except Aylesbury. It is recorded by H. B. Woodward as *Nodosaria* cf. *raphanistrum* [Linn.], and the specimens in Aylesbury Museum from the collection of the late Dr. Lee, of Hartwell House, have this label. Chapman records the form as *N. raphanus* from Hartwell. It ranges from the Lias and occurs at the present day at depths down to 1,100 fathoms (Brady).

Localities: Hartwell (c.); Bierton (r.); Whitchurch (r.); Long Crendon (a.); Wheatley and Shotover Hill, bed 2 (a.), bed 1 (r.).

Nodosaria seminuda Reuss. (Pl. IX, Fig. 1.)

Dentalina seminuda Reuss, 1850; *Denkschr. Akad. Wiss. Wien.*, vol. i, p. 367, pl. xlvi, fig. 9.

Nodosaria seminuda Bagg, 1912; *U.S. Geol. Surv.*, Bull. 513, p. 59, pl. xvi, fig. 3.

A single well-developed specimen shows similarity with *N. seminuda* Reuss. The lower portion of the test is costate, the later chambers smooth; the early septa are hardly visible, but the later part of the test is more constricted, the last chamber being almost globular. The species is therefore a catagenetic form, showing loss of ornament (costate to smooth). It lives at present in the Caribbean Sea (Bagg), and does not appear to have been recorded below the Tertiary.

Locality: Hartwell (v.r.).

Nodosaria (*Gl.*) *humilis* Roemer. (Pl. IX, Figs. 2, 3.)

N. humilis Roemer, 1841; *Verst. norddeutsch. Kreide*, p. 95, pl. xv, fig. 6.

N. humilis Chapman, 1893; *Journ. Roy. Micr. Soc.*, p. 585, pl. viii, fig. 18.

This form is very variable in its distribution at different localities. All specimens from Hartwell preserve a regularly conical outline due to the feeble inflation of the segments; in certain individuals which are much longer, a greater number of chambers is developed than in the type. *N.* (*Gl.*) *humilis* has been recorded from the Upper Hils Clay, the Speeton Clay, and Gault of North Germany (Roemer, Reuss), from the Gault of Folkestone (Chapman), and the Gault of France (Berthelin), as well as from later deposits.

Localities: Hartwell (c.); Long Crendon (c.); Wheatley, bed 2 (v.r.).

FRONDICULARIA Defrance, 1824.

Frondicularia concinna Koch. (Pl. IX, Fig. 5.)

Frondicularia concinna Koch, 1851; *Palaeontographica*, vol. i, p. 172, pl. xxiv, fig. 5.

F. concinna Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 54, pl. iv, fig. 13.

The Hartwell Clay specimens differ from the previously figured specimens in that the greatest width is nearer the initial end, and the outline is more irregular. *F. concinna* is recorded from the Upper Hils and Speeton Clay of Germany (Reuss).

Localities: Wheatley, bed 2 (f.); Shotover Hill, bed 1 (r.); Bierton (v.r.).

Frondicularia granulata Terquem.

Frondicularia granulata Terquem, 1863; *Mém. Ac. Imp. Metz.*, vol. xliv, p. 379, pl. vi, fig. 20.

Only one specimen of this species was found in the beds under discussion. Previously *F. granulata* has only been recorded from the Lias (Terquem).

Locality: Shotover Hill, bed 1 (v.r.).

Marginulina d'Orbigny, 1826.

Marginulina Jonesi Reuss.

Marginulina Jonesi Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 61, pl. v, fig. 19.

M. Jonesi Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 163, pl. iv, fig. 24.

M. Jonesi Sherlock, 1914; Geol. Mag., p. 259, pl. xviii, fig. 15.

The individuals of this form differ considerably with regard to the number of chambers, but on the whole agree well with the published figures. Sherlock regards *M. Jonesi* as "a mere variety of *M. costata* (Batsch) characterized by fewer and more marked ribs", but he retains the specific name. Originally described from the Upper Hils of Germany (Reuss), it has since been found in the Gault of Folkestone (Chapman), the Speeton Clay of Yorkshire (Sherlock), and the Hartwell Clay (Chapman).

Localities: Hartwell (a.); Bierton (r.); Long Crendon (v.r.); Wheatley and Shotover Hill, beds 1 and 2 (c.).

Marginulina linearis Reuss.

Marginulina linearis Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 60, pl. v, fig. 15.

M. linearis Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 161, pl. vi, fig. 14.

This form has been recorded from the *Minimus*-clay of North Germany (Reuss), the French Gault (Berthelin), Gault of Folkestone (Chapman), and the Speeton Clay of Yorkshire (Sherlock). It occurs also in the Oxford Clay of Buckinghamshire (see later).

Localities: Hartwell (r.); Shotover Hill, bed 1 (v.r.).

Vaginulina d'Orbigny, 1826.

Vaginulina discors Koch. (Pl. IX, Fig. 6.)

Vaginulina discors F. Koch, 1851; *Palæontographica*, vol. i, p. 172, pl. xxiv, figs. 1, 2.

V. discors Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 50, pl. iii, figs. 10–12.

V. discors Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 426, pl. viii, fig. 13.

Chapman recorded *V. discors* from the Hartwell Clay in 1897. The specimens found by the present writer are characterized by depressed septal lines and striated segments, but they lack the strong longitudinal ribs which are shown in figures by Reuss and Chapman. They differ in this respect also from *V. sparsicostata* Reuss. For the present, however, it seems advisable to retain them under the name *V. discors*, as they agree well with Chapman's

figured specimen from the Gault of Folkestone, now in the Jermyn Street Museum. This species is recorded from the Speeton Clay of Germany (Reuss) and the Gault of Folkestone (Chapman).

Localities: Hartwell (c.), Aylesbury (v.r.), Wheatley, bed 2 (f.), Bierton (r.), Long Crendon (r.).

Vaginulina harpa Roemer. (Pl. IX, Fig. 7.)

Vaginulina harpa Roemer, 1841; *Verst. norddeutsch. Kreide*, p. 96, pl. xv, fig. 13.
V. harpa Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 51, pl. iv, figs. 5–7.

Specimens from the Hartwell Clay referred to this species are very variable in outline, but the type of ribbing is constant. *V. harpa* is recorded from the Upper Hils and Speeton Clay of Germany (Reuss), the Lower Portland of Bucks (H. B. Woodward), the Hartwell Clay (Chapman), and older Jurassic deposits (see later).

Localities: Hartwell (c.); Aylesbury (f.); Bierton (r.); Whitchurch (f.); Long Crendon (v.r.); Wheatley and Shotover Hill, bed 2 (c.), bed 1 (a.).

Vaginulina incompta Reuss. (Pl. IX, Fig. 4.)

Vaginulina incompta Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 45, pl. iii, fig. 5.
V. incompta Sherlock, 1914; Geol. Mag., p. 260, pl. xix, fig. 10.

One specimen from the Hartwell Clay is referred to this species, which is recorded from the Upper Hils of Germany (Reuss) and the Speeton Clay of Yorkshire (Sherlock).

Locality: Hartwell (v.r.).

Vaginulina legumen (Linn.).

Nautilus legumen Linné, 1758; *Syst. Nat.*, 10th ed., p. 711, No. 248; 1767, 12th ed., p. 1164, No. 288.
Vaginulina legumen Brady, 1884; *Chall. Rep.*, vol. ix, p. 530, pl. lxvi, figs. 13–15.

This species ranges from Triassic to Recent. It is common in existing seas in shallow water (to 2,000 fath.), and is occasionally found in deep water (Brady).

Locality: Hartwell (v.r.).

Cristellaria Lamarck, 1816.

Cristellaria humilis Reuss.

Cristellaria humilis Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 65, pl. iv, fig. 16, 17.
C. humilis Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 648, pl. ix, fig. 7.

This form was originally described from the Upper Hils of Germany, and has since been recorded from the Gault of Folkstone (Chapman) and the Hartwell Clay (Chapman).

Localities: Hartwell (c.); Long Crendon (v.r.); Wheatley, bed 2 (f.); Shotover Hill, bed 1 (a.).

Cristellaria italica (Defr.).

Saracenia italica Defrance, 1824; *Dict. Sci. Nat.*, xxxii, 177; xlvii, 334; *Atlas Conch.*, xiii, 6.
Cristellaria italica Brady, 1884; *Chall. Rep.*, vol. ix, p. 545, pl. lxviii, figs. 17, 20–23.
C. italica Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 653, pl. x, fig. 10.

Specimens of *C. italica* from the Hartwell Clay resemble those from the Gault of Folkestone in having sharp edges and a distinct keel. Some elongated specimens approach *C. bononiensis* Berth., but preserve the spiral commencement. Ranging from the Lias upwards, the species has already been recorded from the Hartwell Clay (Chapman). It also occurs in the Gault of Folkestone (Chapman), and the Aptian of Surrey (Chapman). At the present day it is found in shallow water at depths varying from 90 fathoms in the Mediterranean to 725 fathoms in the North Atlantic (Brady).

Localities: Hartwell (a.); Aylesbury (c.); Bierton (c.); Long Crendon (a.); Whitchurch (f.); Wheatley and Shotover Hill, bed 2 (a.), bed 1 (c.).

Cristellaria sulcifera Reuss.

Cristellaria sulcifera Reuss 1862; *Sitz. d. Akad. Wiss. Wien*, vol. xlvi, pp. 74-93, pl. viii, fig. 8.
C. sulcifera Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 650, pl. x, fig. 2.

This form often approaches *C. italica*, with which it appears to be connected by transition-forms, but typical specimens are easily distinguished by the grooved sutural lines. *C. sulcifera* has been recorded from the *Minimus*-clay of Germany (Reuss), Aptian of Surrey, Gault of Folkestone, and the Hartwell Clay (Chapman).

Localities: Hartwell (f.); Wheatley, bed 2 (r.).

Cristellaria navicula d'Orb.

Cristellaria navicula d'Orbigny, 1840; *Mém. Soc. Géol. Fr.*, ser. 1, vol. iv, p. 27, pl. ii, figs. 19, 20.
C. navicula Reuss, 1845; *Verstein. böhm. Kreidef.*, pt. i, p. 34, pl. xii, fig. 27.
C. navicula Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 650, pl. x, fig. 1.

Recorded from the Hartwell Clay (Chapman), *C. navicula* occurs in the Gault of Monteley (Berthelin), the Gault of Folkestone (Chapman), and many Upper Cretaceous faunas.

Localities: Hartwell (f.); Long Crendon (v.r.); Wheatley, bed 2 (r.).

Cristellaria convergens Bornemann.

Cristellaria convergens Bornemann, 1855; *Zeitschr. deutsch. geol. Gesellsch.*, vol. vii, p. 327, pl. xiii, figs. 16, 17.
C. convergens Brady, 1884; *Chall. Rep.*, vol. ix, p. 546, pl. lxix, figs. 6, 7.
C. convergens Chapman, 1896; *Journ. Roy. Micr. Soc.*, p. 4, pl. i, fig. 6

Chapman has already noted this form from Hartwell. It is also recorded from the Tertiary of Hermsdorf (Bornemann), the Gault of Folkestone (Chapman), and the Aptian of Surrey (Chapman). At the present day it is characteristically a deep-water form.

Localities: Hartwell (f.); Aylesbury (v.r.); Long Crendon (f.).

Cristellaria complanata Reuss.

Cristellaria complanata Reuss, 1845; *Verstein. böhm. Kreidef.*, pt. i, p. 33, pl. xiii, fig. 54.
C. complanata Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 92, pl. xii, fig. 13.
C. complanata Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 653, pl. x, fig. 12.

Originally described from the Plänermergel of Bohemia, this

species has been recorded from the Gault of Folkestone (Reuss, Chapman), and the Aptian beds of Surrey (Chapman).

Localities: Hartwell (v.r.); Whitchurch (v.r.); Long Crendon (v.r.).

Cristellaria fragraria (Gümbel). (Pl. IX, Figs. 9, 10.)

Marginulina fragraria Gümbel, 1868; *Abh. m.-ph. Cl. k.-bayer Ak. Wiss.*, vol. x, p. 635, pl. i, figs. 58*a–c*.

Cristellaria fragraria Burrows & Holland, 1897; *Proc. Geol. Assoc.*, vol. xv, p. 38, pl. iii.

Numerous specimens from Long Crendon agree with Gümbel's figure 58*a*, and with the series of figures given by Burrows & Holland. Specimens from Hartwell have a different development in the younger portions of the test which is more elongated and more constricted at the septa, the chambers being more globular (cf. Gümbel's figure 58*c*). The tubercles which ornamented the earlier septa are not seen in the later part of the test, whereas longitudinal striæ are here developed. Both forms, therefore, agree in showing catagenesis of ornament, from tuberculate to striate, but the later (Hartwell) form exhibits a more advanced degree of uncoiling. *C. fragraria*, which is abundant in the London Clay, has already been noted from the Hartwell Clay (Chapman). It also occurs in the Nummulitic Marl of the Bavarian Alps (Gümbel), and in the *Clavulina Szabói* beds of Hungary (Hantken). Recent specimens were obtained from Torres Str. (155 fath.) and off the coast of S. America (350 fath.) only (Brady).

Localities: Hartwell (a.); Bierton (v.r.); Long Crendon (a.); Wheatley, bed 2 (v.r.).

Cristellaria cultrata (Montfort).

Robulus cultrata Montfort, 1808; *Conchyl. Syst.*, vol. i, p. 214.

Cristellaria cultrata Brady, 1884; *Chall. Rep.*, vol. ix, p. 550, pl. lxx, figs. 4–6.

C. cultrata Sherlock, 1914; Geol. Mag., p. 262, pl. xix, fig. 4.

This species, which ranges from the Lias to the present day, was noted from Hartwell by Chapman. It is a common form and has been recorded from most of the Jurassic and Cretaceous deposits. At the present day it has a world-wide distribution and is found at all depths (Brady).

Localities: Hartwell (a.); Aylesbury (a.); Bierton (a.); Whitchurch (c.); Long Crendon (v.r.); Wheatley (a.); Shotover Hill (r.).

Cristellaria Roemeri Reuss. (Pl. IX, Fig. 8.)

C. Roemeri Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 75, pl. viii, fig. 9.

Numerous rotulate Cristellarians with limbate sutures are referred to this species which was found by Reuss in the Middle Hils, Specton Clay, and *Minimus*-clay of Germany. It does not appear to have been recorded since.

Two specimens from Wheatley show a decided tendency towards uncoiling; these are referred to *C. Roemeri* for the present, until more material is available for study.

Localities : Hartwell (a.) ; Aylesbury (r.) ; Bierton (r.) ; Wheatley, bed 2 (a.).

Cristellaria gibba d'Orb.

C. gibba d'Orbigny, 1839 ; *Foram. Cuba*, p. 63, pl. vii, fig. 20.
C. gibba Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 546, pl. lxix, figs. 8, 9.
C. gibba Chapman, 1896 ; *Journ. Roy. Micr. Soc.*, p. 4, pl. i, fig. 7.
C. gibba Sherlock, 1914 ; Geol. Mag., p. 261, pl. xix, fig. 9.

This species ranges from the Lias to the present day, and is recorded from many of the Lower Cretaceous deposits as well as from the Hartwell Clay (Chapman). It is recorded living from the North Atlantic and South Pacific at depths of less than 500 fathoms, "but this is probably only a small portion of the area it inhabits" (Brady).

Localities: Hartwell (c.) ; Long Crendon (f.).

Cristellaria crepidula (F. & M.).

Nautilus crepidula Fichtel & Moll, 1798 ; *Test. Micr.*, p. 107, pl. xix, figs. *g–i*.
Cristellaria crepidula d'Orbigny, 1839 ; *Foram. Cuba*, p. 64, pl. viii, figs. 17–18.
C. crepidula Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 542, pl. lxvii, figs. 17, 19, 20 ; pl. lxviii, figs. 1, 2.
C. crepidula Chapman, 1894 ; *Journ. Roy. Micr. Soc.*, p. 648, pl. ix, fig. 8.

Under this name are included the strongly compressed, non-carinate, elongate Cristellarians, with depressed septal lines and narrow, almost vertical septal face. The form shows considerable variation of outline, and this variation is so gradual that no strict identification of the numerous "species" can be made. Ranging from the Lias, *C. crepidula* is now found in all existing seas and at all depths, but is nowhere very abundant (Brady).

Localities : Hartwell (c.) ; Bierton (r.) ; Wheatley and Shotover Hill, bed 2 (c.), bed 1 (r.).

Subfamily POLYMORPHINÆ.

Polymorphina d'Orbigny, 1826.

Polymorphina fusiformis Roemer.

Polymorphina (*Globulina*) *fusiformis* Roemer, 1838 ; *Neues Jahrb.*, p. 386, pl. iii, fig. 37.
P. fusiformis Chapman, 1896 ; *Journ. Roy. Micr. Soc.*, p. 11, pl. ii, fig. 9.
P. fusiformis Sherlock, 1914 ; Geol. Mag., p. 263, pl. xix, fig. 12.

The question of nomenclature of this variable form has been discussed by Chapman (1896, p. 11) and Sherlock (1914, p. 264). The species is recorded from the Upper Hils and *Minimus*-clay of Germany (Reuss), Gault of France (Berthelin), and the Gault of Folkestone (Chapman). It still lives at depths down to 2,400 fathoms (Brady).

Localities : Hartwell (v.r.) ; Wheatley, bed 2 (v.r.) ; Shotover Hill, bed 1 (v.r.).

Family GLOBIGERINIDÆ.

GLOBIGERINA d'Orbigny, 1826.

Globigerina marginata, Reuss.

Rosalina marginata Reuss, 1845 ; *Verstein. böhm. Kreid.*, pt. i, p. 36, pl. xiii, fig. 47.
Globigerina marginata Reuss, 1874 ; In Geinitz, *Palæontographica*, xx (2), p. 112, No. 2.
G. marginata Brady, 1879 ; *Q.J.M.S.*, vol. xix, n.s., p. 74.
G. marginata Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 597.

This form, which closely resembles its isomorph *Pulvinulina menardi* d'Orb., is recorded from Hartwell by Chapman. It was previously restricted to the Cretaceous as a fossil form, being found originally in the Chalk of Bohemia (Reuss). It is very rare in Recent deposits (Brady).

Localities : Hartwell (f.) ; Wheatley, bed 2 (a.).

Globigerina cretacea d'Orb.

Globigerina cretacea d'Orbigny, 1840 ; *Mém. Soc. Géol. Fr.*, ser. i, vol. iv, p. 34, pl. iii, figs. 12–14.
G. cretacea Chapman, 1896 ; *Journ. Roy. Micr. Soc.*, p. 588, pl. xiii, figs. 5, 6.

Several small specimens are placed in this species, which is a characteristic Cretaceous form. It is common in all zones of the Gault of Folkestone (Chapman), and ranges into modern times (Brady). This is the first record of the species below the Cretaceous.

Locality : Hartwell (f.).

Family ROTALIIDÆ.

Subfamily ROTALIINÆ.

PULVINULINA Parker & Jones, 1862.

One specimen from Long Crendon belongs to this genus, but it is so badly worn that specific determination is not possible. The rarity of Pulvinulinæ in the Hartwell Clay is in sharp contrast with the abundance of the genus in the Speeton Clay of Yorkshire.

COMPARISON WITH OTHER DEPOSITS OF THE DISTRICT.

For purposes of comparison various deposits near Aylesbury were examined for Foraminifera, and the results are given below :—

Lower Gault.—Ford, 4 miles S.W. of Aylesbury. Dark-blue clay with abundant grains of quartz, glauconite, and phosphatic material, formerly worked for "coprolites". Over 130 species of Foraminifera were found by the writer and Mr. Hollis, of Aylesbury.[1] There are minor differences in distribution as compared with the Gault Foraminifera from Folkestone. The following fourteen species occur in the Gault at Ford and also in the Hartwell Clay. *Reophax scorpiurus* Montf. (v.r.); *Haplophragmium acutidorsatum* Hantken (f.); *Thurammina albicans* Brady (r.) ; *Nodosaria* (*Gl.*) *humilis* Roem. (r.) ; *N.* (*D.*) *fontannesi* Berth. (v.r.) ; *Marginulina linearis* Reuss (r.) ; *M. Jonesi* Reuss (r.) ; *Cristellaria humilis* Reuss (v.r.) ; *C. navicula*

[1] *The Naturalist*, July, 1921, pp. 235–240.

d'Orb. (v.r.); *C. sulcifera* Reuss (v.r.); *C. italica* (Defr.) (v.r.); *C. gibba* d'Orb. (f.); *C. complanata* Reuss (v.r.); *Polymorphina fusiformis* (Roem.) (f.); The commonest species are *Anomalina ammonoides* (Reuss) and *Globigerina cretacea* d'Orb., which outnumber all the other species put together. Mr. Hollis has prepared a series for the Bucks County Museum at Aylesbury.

Upper Portland.—Long Crendon. A cream-coloured marl, locally known as "Wychert" or "Witchet", was examined, but yielded no Foraminifera. Ostracods are plentiful.

Kimmeridge Clay (*latissima-beds*).—Stewkley. Dark shale which could not be satisfactorily broken up. No Foraminifera were found.

Kimmeridge Clay (*virgula*-beds).—Brill. A small sample of the clay sent to the writer contained a few Foraminifera, but the relative abundance cannot be judged on such scanty material. The following species occur: *Haplophragmium* sp.; *Nodosaria raphanus* (Linn.); *Vaginulina harpa* Roem.: *Cristellaria italica* (Defr.); *C. crepidula* (F. & M.); *C. rotulata* (Lam.); *Pulvinulina* sp. Dr. A. Morley Davies[1] has noted Foraminifera from this locality, but they were not identified specifically. The five species fully identified above occur also in the Hartwell Clay.

Oxford Clay (pre-*cordatum* zone).—Quainton Road Junction. A sandy clay containing much quartz yielded abundant Foraminifera. The list of species is given in full, as the Oxford Clay forms do not appear to have been recorded previously.

Species and relative abundance in the Oxford Clay of Quainton (Bucks).		*Geological range as previously recorded.*
**Haplophragmium* cf. *aequale* (Roem.)	a.	L. Cretaceous.
Nodosaria communis	v.r.	Permian to Recent.
Lingulina carinata	c.	Lias to Recent.
Frondicularia cf. *varians* Terquem	f.	Lias.
Flabellina Deslongchampsi Terquem	f.	Lias.
Rhabdogonium sp.	r.	
Marginulina linearis Reuss.	f.	L. Cretaceous.
**Vaginulina harpa* Roem.	f.	Hartwell Clay—L. Cret.
,, cf. *discors* Koch.	r.	Hartwell Clay—Gault.
**Cristellaria crepidula* (F. & M.)	c.	Lias to Recent.
* ,, *cultrata* (Montf.)	f.	Lias to Recent.
,, *gracillissima* Reuss	v.r.	L. Cretaceous.
,, *gibba* d'Orbigny	c.	Lias to Recent.
**Polymorphina fusiformis* Roemer	f.	Lias to Recent.
Vitrivebbina irregularis (Auctt.)	a.	Lias to Oxford Clay.
Pulvinulina sp.	a.	

* Occurs also in the Hartwell Clay.

General Conclusions.

The Foraminifera from the Hartwell Clay above described comprise thirty-seven species belonging to thirteen genera, and may be tabulated as follows:—

[1] *Q.J.G.S.*, vol. lxiii, 1907, p. 32.

		Number of species.	
		Chapman, 1897.	*Neaverson*, 1921.
Lituolidæ.	*Reophax*	—	1
	Haplophragmium	—	2
	Thurammina	—	2
Textulariidæ.	*Tritaxia*	1	—
Lagenidæ.	*Lagena*	1	4
	Nodosaria	1	4
	Frondicularia	—	2
	Marginulina	1	2
	Vaginulina	2	4
	Cristellaria	8	11
	Polymorphina	—	1
Globigerinidæ.	*Globigerina*	1	2
Rotalidæ.	*Pulvinulina*	—	1
		7 genera.	12 genera.
		15 species.	36 species.

In order to analyse the results Chapman's list (*Proc. Geol. Assoc.*, vol. xv, 1897, p. 97) is merged with the new record, as the Hartwell forms have not been fully described before.

Thirty-seven species of Foraminifera have been found in the Hartwell Clay and associated clays. Of these one form is not specifically identified, so will not be further considered. Thirteen (or 36 per cent) of the remaining thirty-six species were recorded from Jurassic deposits older than the Hartwell Clay, whilst twenty-three (or 64 per cent) were not known below the Cretaceous before the publication of Chapman's list. Further, twenty-two of the thirty-six species occur in the Gault of Folkestone, twelve in the Bargate Beds (Aptian) of Surrey, ten in the Speeton Clay of Yorkshire, and thirteen in the Lower Cretaceous of Germany. This confirms Chapman's general statement that the Foraminifera of the Hartwell Clay "present a facies comparable with that of the Neocomian (*sic*) and Gault". The relation is seen more especially with regard to the *Cristellariæ*, which are represented in the Hartwell Clay by eleven species, eight of which are characteristic Lower Cretaceous forms. Other Hartwell forms connecting with the Lower Cretaceous are *Globigerina marginata*, *Vaginulina incompta*, and *Haplophragmium acutidorsatum*. The *Vaginulinæ*, however, present a general Jurassic facies: the commonest species, *V. harpa*, with its strong longitudinal ribbing, forming a marked contrast with the typical *Vaginulinæ* of the Gault which possess projecting sutures and marginal angles. In *V. discors* of the Hartwell Clay the longitudinal ribbing is not so conspicuous, but the limbate sutures and margins are still lacking. *Cristellaria* and *Vaginulina* are the dominant genera in the Hartwell Clay, and it is interesting to find the former represented by Cretaceous species, whilst the latter genus has a Jurassic aspect.

It is more difficult to compare the Hartwell Clay Foraminifera with those from older Jurassic deposits, as the latter have been somewhat neglected. The series from the Kimmeridge Clay and Oxford Clay of Bucks show a marked difference in the assemblage

of Cristellarians. In these deposits the ensiform Cristellarians abound, whilst the rotulate varieties (which predominate in the Hartwell Clay) are subordinate. The occurrence (though rare) of *Cristellaria gracillissima* in the Oxford Clay is noteworthy, as its previous lowest record is from the Speeton Clay of Yorkshire (Sherlock, 1914). The only common *Vaginulina* in the Oxford and Kimmeridge Clays of Bucks is *V. harpa*, though *V. discors* also occurs. These belong to the group with strong longitudinal ribs which, according to Berthelin, had its maximum development in Jurassic times. *Marginulina linearis* occurs in both the Hartwell Clay and the Oxford Clay of Bucks; this is the first record of the species below the Speeton Clay.

A noteworthy feature of the Oxford Clay Foraminifera from Quainton is the great abundance of the arenaceous form, *Haplophragmium* cf. *aequale*, which exceeds in numbers all the other species collectively. In the Hartwell Clay arenaceous forms are uncommon. Porcellanous forms are not found in the Hartwell Clay, but the Gault of Ford is remarkably rich in *Spiroloculina* and *Miliolina*, whilst *Vitriwebbina irregularis* is abundant in the Oxford Clay of Quainton. Thus the main features of the foraminiferal assemblages may be tabulated as follows:—

Bucks. deposits.	*Cristellaria.*	*Vaginulina.*	*Arenacea.*	*Porcellanea.*
Gault.	Rotulate varieties.	Limbate and marginate.	Rare.	*Spiroloculina* and *Miliolina*.
Hartwell Clay.	Rotulate varieties.	Longitudinally ribbed.	Rare.	None.
Oxford Clay.	Ensiform varieties.	Longitudinally ribbed.	*Haplophragmium* cf. *aequale*, abundant.	*Webbina irregularis* Auctt.

A distinctive feature of the Hartwell Clay assemblage is the frequent occurrence of *Cristellaria fragraria*, which has hitherto been regarded as a characteristic Tertiary form. It is common at two horizons in the Hartwell Clay, and specimens from the higher bed show a more advanced degree of outcoiling than those from the lower. The occurrence of similar forms at widely separated horizons suggests that these forms should not be included under the same specific name. They may be "morphic equivalents" arising from different stocks and thus analogous with homœomorphic forms of Ammonites which are at least generically distinct. This question cannot be decided until more is known of the evolution and development of the Foraminifera.

The Tithonian Stramberg limestone, a deposit of approximately the same age as the Hartwell Clay, contains fourteen species belonging to seven genera.[1] The dominant forms are two arenaceous species (*Ammodiscus incertus* and *Involutina remesiana*) and the cosmopolitan

[1] Chapman, *Linn. Soc. Journ. Zool.*, vol. xxviii, 1900, p. 28. Perner, *Bull. Acad. Sci. Bohême*, 1898, p. 1.

TABLE SHOWING DISTRIBUTION OF THE FORAMINIFERA OF THE HARTWELL CLAY IN SOME OTHER DEPOSITS.

	Species.	*Range in time as previously known.*	*Depth (in fathoms) now living.*	*Gault, Folkestone.*	*Aptian, Surrey.*	*Speeton Clay, Yorkshire.*	*Lower Cretaceous of Germany.*	*Oxford Clay, Bucks.*
1.	*Reophax scorpiurus* Montf.	Jur.–Rec.	Any.	1		1		
2.	*Haplophragmium acutidorsatum* Hantken.	L. Cret.–Rec.	Shallow.	2	2			
3.	*H. aequale* (Roem.)	L. Cret.	—	3			3	3
4.	*Thurammina albicans*, Brady	U. Jur.–Rec.	1,900.	4				
5.	*T. papillata* Brady	U. Jur.–Rec.	Deep water.					
6.	*Tritaxia* (?) *variabilis* (Brady)	Hartwell Clay to Rec.	Shallow.					
7.	*Lagena hispida* Reuss.	M. Lias.–Rec.	To 1900.	7				
8.	*L. laevis* (Montague)	Sil.–Rec.	Any.	8	8	8		
9.	*L. sulcata* (Walker & Jacob)	Sil.–Rec.	To 2,750.					
10.	*L. apiculata* Reuss	Lias.–Rec.	To 2,750.					
11.	*Nodosaria raphanus* (Linn.)	U. Trias.–Rec.	To 1,400.					
12.	*N. seminuda* Reuss	Plioc.–Rec.	Shallow.					
13.	*N. (D.) fontannesi* Berthelin	L. Cret.	—	13	13	13		
14.	*N. (Gl.) humilis* Roem.	Lias.–Eocene.	—	14			14	
15.	*Frondicularia concinna* Reuss.	Cretaceous.	—				15	
16.	*F. granulata* Terq.	Lias.	—					
17.	*Marginulina Jonesi* Reuss	Hartwell Clay to Chalk Marl.	—	17	17	17	17	
18.	*M. linearis* Reuss.	L. Cret.	—	18	18	18	18	18
19.	*Vaginulina incompta* Reuss	L. Cret.	—			19	19	
20.	*V. legumen* (Linn.)	Lias.–Rec.	To 2,000.		20			
21.	*V. harpa* Roem.	Hartwell Clay–L. Cret.	——				21	21
22.	*V. discors* Koch	Hartwell Clay–Gault.	—	22			22	22
23.	*Cristellaria italica* (Defr.)	Hartwell Clay–Recent.	To 725.	23	23			
24.	*C. varicula* d'Orb.	Hartwell Clay–Chalk.	—	24				
25.	*C. calcifera* (Reuss)	Hartwell Clay to Gault.	—	25	25		25	25
26.	*C. fragraria* (Gümbel)	Hartwell Clay–Recent.	155 (Torres St. 350 (S. Amer.)					
27.	*C. humilis* Reuss	Hartwell Clay–Gault.	—	27			27	
28.	*C. convergens* Born.	Hartwell Clay–Rec.	Deep water.	28	28			
29.	*C. calcarata* (Montf.)	Lias.–Rec.	rarely < 100.	29	29	29		29
30.	*C. Roemeri* Reuss	L. Cret.	—				30	
31.	*C. gibba* d'Orb.	Lias.–Rec.	< 500	31	31	31	31	
32.	*C. complanata* (Reuss)	L. Cret.	—	32	32			
33.	*C. crepidula* (Fitchel & Moll)	Lias.–Rec.	To 2,350.	33	33	33		33
34.	*Polymorphina fusiformis* (Roem.)	Lias.–Rec.	To 2,400.	34		34	34	34
35.	*Globigerina marginata* (Reuss)	Cretaceous.						
36.	*G. cretacea* d'Orb.	Cret.–Rec.	Any.	36	36			

species, *Cristellaria rotulata*, *C. gibba*, and *C. cultrata*. A specimen of *Vaginulina truncata* and one of *Haplophragmium neocomiana* connect the assemblage with the Lower Cretaceous. The only point of comparison with the Hartwell Clay is in the occurrence of the Cristellarians mentioned above. The Upper Jurassic of Switzerland has yielded arenaceous forms referred by Haeusler to *Thurammina albicans*, and similar forms are occasionally found in the Hartwell Clay.

Of the thirty-six species from the Hartwell Clay, thirteen (or 36 per cent) are known from the Hils of Germany. The foraminiferal assemblages of the two deposits are connected by (1) the dominance of *Cristellaria* and *Vaginulina*, and (2) the comparative rarity of arenaceous forms. A notable difference is the presence of twelve species of *Nodosaria* in the Hils against four in the Hartwell Clay. *Lagena* is not represented in the Hils assemblage, but four species occur in the Hartwell Clay.

The Foraminifera throw little light upon the question of the depth at which the Hartwell Clay was deposited. Nineteen of the thirty-six species are still living and eleven of these are recorded by Brady from both shallow and deep water. Of the eight species remaining, three, *Thurammina albicans*, *T. papillata*, and *Cristellaria convergens*, are characteristic of deep water, whilst five occur in shallow water. The balance of the evidence seems to be in favour of fairly deep water, since tests of shallow water forms could sink to the level of deposition. The Hartwell Clay itself shows great similarity with the Gault Clay both in the abundance of glauconite and in the presence of certain species of Foraminifera. Thus it is permissible to suppose that the depth of deposition would be similar, viz. between 800 and 900 fathoms according to Chapman's calculation for the depth of the Gault Sea.[1]

Summary.

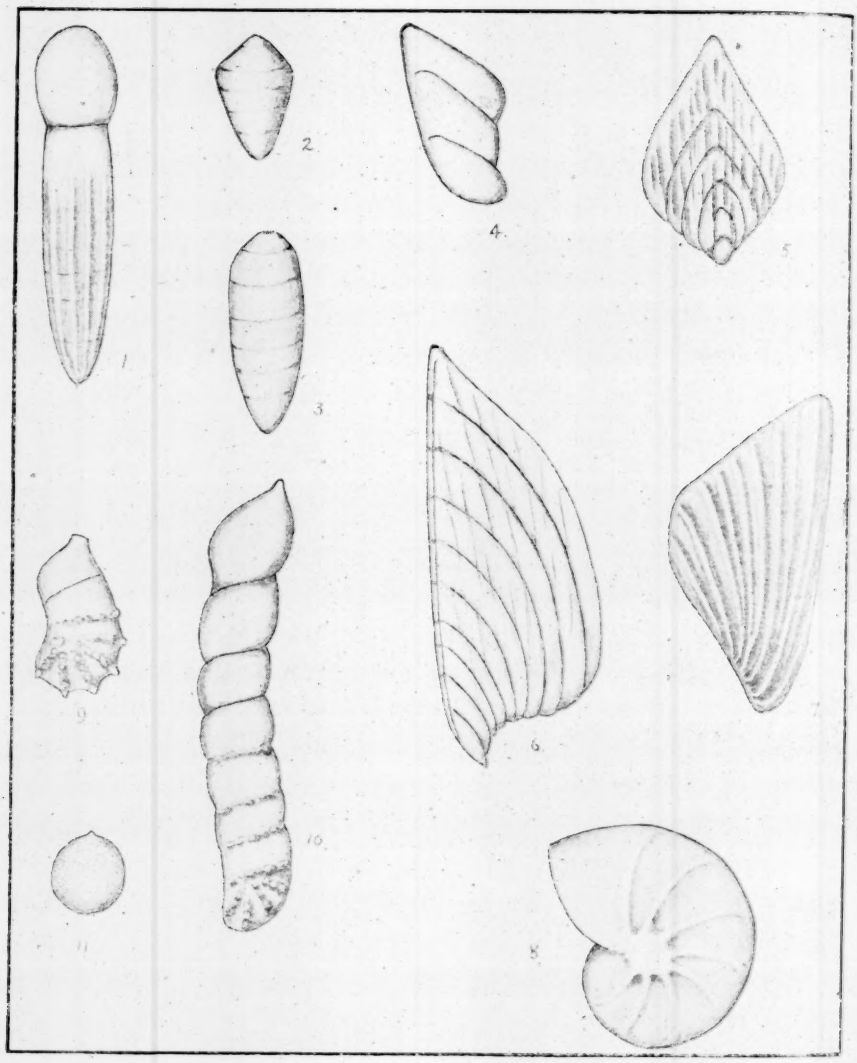
1. Thirty-six species of Foraminifera are recorded from various localities in the Hartwell Clay and associated beds.

2. The assemblage of species is characterized by :—
   (*a*) the abundance of rotulate Cristellarians of Lower Cretaceous type, and of *Cristellaria fragraria*.
   (*b*) the common occurrence of *Vaginulina harpa*, a Jurassic type.
   (*c*) the rarity of arenaceous, and the absence of porcellanous forms.

3. The Foraminifera from the Hartwell Clay are compared with those from other deposits in the Aylesbury district, and with those from foreign deposits of similar age.

4. The relative abundance of glauconite is a point of similarity between the Hartwell Clay and beds hitherto regarded as Kimmeridge Clay.

[1] *Nat. Sci.*, vol. xiii, 1898, No. 81, p. 305.



E. Neaverson, del. ad nat.

FORAMINIFERA, HARTWELL CLAY, BUCKS.

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EXPLANATION OF PLATE IX.

Photograph of *camera lucida* drawings of Foraminifera. All figures are magnified 30 diameters.

FIGS.

1.—*Nodosaria seminuda* Reuss. Hartwell Clay, Hartwell.
2.—*N.* (*Gl.*) *humilis* Roemer. Hartwell Clay, Long Crendon.
3.—*N.* (*Gl.*) *humilis* Roemer. Hartwell Clay, Hartwell.
4.—*Vaginulina incompta* Reuss. Hartwell Clay, Hartwell.
5.—*Frondicularia cincinna* Reuss. "Kimmeridge Clay," Wheatley.
6.—*Vaginulina discors* Koch. Hartwell Clay, Hartwell.
7.—*V. harpa* Roemer. Hartwell Clay, Long Crendon.
8.—*Cristellaria Roemeri* Ruess. Hartwell Clay, Hartwell.
9.—*C. fragraria* Gümbel (short form). Hartwell Clay, Long Crendon.
10.—*C. fragraria* Gümbel (long form). Hartwell Clay, Hartwell.
11.—*Thurammina albicans* Brady. Hartwell Clay, Hartwell.

NOTE.—A series of specimens is deposited in the Bucks County Museum, Aylesbury, and therefore only a few of the more characteristic forms are figured here.

On a Local Alteration in Limestone Shales at Wensley, Derbyshire.

By C. S. GARNETT.

A SMALL stream forms the boundary between the Parishes of Wensley and Winster, on the north-west of the former; and hereabouts its bed, in the Limestone Shale, is probably about 30 feet above the Carboniferous Limestone. On the Winster side, the shales form a wooded slope (Whites Wood) rising 100 feet in about 200 feet, and on this side the shale is quite normal and of the black colour usual in the lower beds of this formation. On the Wensley side the ground rises more gradually, and the actual bank of the stream averages not more than about 10 feet in height. Here, an altered shale is exposed and can be traced (through the activity of moles) in the fields behind.

There appear to be two small areas of alteration, just over 100 yards apart; and in the case of the larger, of a traceable area of about ½ acre.

At the place of the larger exposure the shale beds are thrown upwards and lie in a confused manner—not unlike the upward bursting caused by the weight of hills behind. On this (the south) side the ground gradually rises from just under 500 feet at the level of the stream, to 1,000 feet in just under half a mile; on the opposite side it rises to 800 feet in a quarter of a mile.

In the areas under consideration the shale in its upper beds, instead of being black in colour, appears bright brick-red from a little distance, and on closer examination is found to be almost white or of a buffish tint within the laminæ, whilst at the surface of these it is quite bright red. This distribution of colouring matter is best seen in the harder portions; where the shale was softer the redness is more evenly distributed in the clay, but the red colouring matter is in places almost or quite absent. The black carbonaceous matter has been completely removed, and

ferruginous substances of the shale—although almost unnoticeable in the normal regions—have been completely changed to the red oxide which remains in a very finely divided state. In some of the material the redness is very vivid, but more than 4% of ferric oxide is seldom present.

As is well known, the Limestone Shales frequently contain, especially towards their base, thin beds of black, earthy limestone; the blackness being, of course, due to carbonaceous (bituminous) matter as in the case of the shales, which, normally, are black at this horizon. A thin slab of this limestone which occurred about the margin of the region of alteration, was itself also bleached in a similar manner. It was grey in colour, almost free from carbonaceous matter, and contained faint streaks and spots of red oxide of iron—evidently resulting from the oxidation of ferruginous matter which previously existed in the rock.

Small phosphatic nodules also occur in some abundance in the Limestone Shales of this district; normally, they are somewhat hard, and in colour uniformly almost black throughout. Some are calcareous and contain about 63% tricalcic phosphate, about 20% calcium carbonate, 3% silica, and some carbonaceous matter. To the unaided vision they show no definite structure, although having a somewhat crystalline appearance. Others are almost free from carbonates; they are harder and consist of compact amorphous calcium phosphate (tricalcic phosphate about 63%) with 20% of silica, and are rather more black in colour. It might be here mentioned that much of the calcium phosphate in the calcareous nodules is seen by microscopical examination not to consist of the amorphous substance, as is the case in the non-calcareous ones and phosphatic nodules generally, but it exists as minute crystalline spherulitic masses of definite material—presumably a variety of apatite.

The nodules which occur in the altered region are themselves also altered in a manner exactly similar to that of the shale. Those which have been completely altered are white throughout, and are soft and friable. In these the carbonaceous matter has been completely removed, and also the carbonates and some phosphate. There remains a white mass containing the siliceous matter, varying amounts of phosphate and also a little sulphate. Although completely altered nodules are not plentiful, two types of incomplete alteration occur abundantly. In one type—that of the originally calcareous nodules—they are soft and friable; the carbonates have been removed, also most of the carbonaceous matter, but not yet much phosphate. On being broken they present a speckled appearance. In the other type—that of the non-calcareous nodules, which in the normal condition are very hard and dense—these nodules occurring in the region of alteration, show an unaltered interior; the bleaching action has been very complete so far as it has proceeded, but this is often only to a depth of about $\frac{1}{2}$ or $\frac{1}{4}$ in. and the zone of alteration is comparatively sharply defined.

In the case of the actual shale also there are two exactly similar types of incomplete alteration. Very occasionally only hard, compact shale laminæ are found which contain a small unaltered portion at their centres; the altering agency not having penetrated so far. The other, entire but incompletely changed, condition is common at the margins. As has been mentioned, at the greatest exposure the beds lie in a confused manner; portions of unaltered black beds have become involved in the altered region, which seems to have consisted of surface beds to a depth of several feet. Alteration continued to take place after the portions of unchanged beds came in contact with the changed ones, but only to a small extent, for at the margins of the black portions the decarbonization can be readily seen to have gradually proceeded a short distance inwards. In this case the shale was soft and readily permeable, and shows a gradual transition in greyness from the edge of the mass to several inches inwards, where visible action is lost. A similar transition may be traced in the actually altered beds, though very much more gradually, as they pass from the region of alteration.

The phenomena of the occurrence very closely correspond with those of burning; i.e. combustion with the complete removal of all carbonaceous matter and oxidation of ferruginous substances.

The nearest known occurrence of igneous rock may be expected at about 150 feet below the top of the limestone, that is, about 180 feet below the surface at this place; it was cut through in the old Mill Close shaft, about ½ mile approximately north-east of the occurrence under consideration, but it has been found to be a contemporaneous flow, and could not be the cause of the burning.

Spontaneous combustion arising from the oxidation of pyrites would seem to be the explanation of the occurrence. However, one or two somewhat peculiar features were noticed, and some work was conducted under the supervision of the author in an endeavour to obtain as much elucidation as possible of available evidence.

In the case of the mass of normal (black) shale in the altered zone, the change is seen to have proceeded distinctly further along the planes of bedding than against them. The mass in question happens to be pushed well into the altered region, but it almost retains the normal horizontal position of the bedding; a small crack had formed almost vertically near its centre, and in this, a commencement of apparently the same change in the shale had taken place, diminishing in extent as it passed downwards exactly as would be expected if the change had been brought about through the action of percolating water.

The question arises, what weathering agent could produce the vast chemical changes involved? From the changes which have taken place in the calcareous phosphatic nodules there is a suggestion of slight acidity—by sulphuric acid, but on consideration the more conspicuous changes would seem to be that of very powerful oxidizing action; indeed, a "wet combustion". Hydrogen peroxide or

ozone in dilute aqueous solution seem to be probably the only agents capable of such vigorous action—at least, under the natural conditions here prevailing.

Wad contains a quantity of manganese dioxide, and, as is well known, the action of sulphuric acid on this results in the liberation of oxygen containing ozone.

Some of the extremely numerous mineral veins in the limestone of the Winster district are famous in Derbyshire for the wad which they contain. Other minerals which are abundant in some of the local veins are pyrites and marcasite, and the readiness with which these are oxidized, with the formation of sulphuric acid as one of the products, is well known. Large quantities of forms of the hydrated ferric oxides also occur in the veins, and much of this is probably of such origin.

Manganese dioxide is not usually regarded as being suitably constituted for the production of hydrogen peroxide, but if it is formed in small quantity, as well as ozonated oxygen by the reaction between the acid and wad, and is carried forward in dilute solution, its action on the organic matter might be expected to be similar to, though less powerful than, that of ozone.

Although ozone is well known to be a most powerful oxidizing substance which attacks and rapidly destroys organic matter, some normal shale was tested with ozone in the laboratory. The shale was crushed and suspended in water, through which oxygen containing ozone was passed in the cold. The ozone readily attacked the organic matter of the shale, with the production of carbon dioxide, and the ready and complete disappearance of all ozone. "Control" experiments were conducted in order that any possible mistaken results would be excluded.

Ozone (or improbably hydrogen peroxide) can be shown (by means of a mixed solution of starch and potassium iodide) to be readily formed by the action of extremely dilute sulphuric acid upon wad; the ozone (and oxygen) entirely passing into solution. Thus, sulphuric acid derived as suggested, on coming in contact with wad, might be expected to give rise to the production of ozone, the solubility of which, in water, is considerable.

On the south of the occurrence of altered shale, which is near the margin of the onset of the shale upon the limestone, the latter rises to 500 feet above the occurrence within half a mile of it. On this slope are almost innumerable small veins containing any or all of the minerals described. The natural drainage level of this area is, of course, the stream mentioned, the former bed of which abruptly marks the horizontal limit of the alteration in this direction. Vertically also, the level of the original bed seems to mark the limit in depth of the alteration, by a rapid but gradual transition. Just above the stream level, in the midst of a completely altered horizon, and between bedding planes of the shale, the action of the slow flowing of percolating water was very noticeable.

If ozone, derived as suggested, was responsible for any of the phenomena noted, perhaps it might be expected that some compound of manganese would be found in the altered zone, and such is the case; clayey matter heavily impregnated with brown oxide of manganese is to be found in some quantity among the altered beds.

Thus, whilst the general phenomena are those of combustion of spontaneous origin such as may arise from the oxidation of pyrites, some of the observations described would perhaps seem to be rather the effect of active percolating water. The actual shales hereabouts do not contain either pyrites or the products of its oxidation in any appreciable quantity, and the ferric oxide in the altered shale is somewhat uniformally distributed in the latter and does not exceed 4%. Thus, if combustion spontaneously arose in such manner, it would seem to have probably done so at a place in closer contact with the limestone veins, and as at the place of exposure the altered beds overlie normal shale at probably about 30 feet above the limestone, the fire would seem to have spread horizontally from such place, which, as the dip is somewhat steep, would be not far distant but would probably involve its passage for a short distance under some beds of shale, leaving them normal and unaltered. The occurrence of brown oxide of manganese in some quantity in the position would be a singular coincidence if simple combustion was the, or the only, cause of the phenomena. Also, with regard to the phosphatic nodules, to account for the condition of the completely altered examples would seem to require some agency other than simple combustion, namely, at least a dilute sulphuric acid solution, and all such examples were found at an obvious water course in the strata at a low horizon in the altered beds.

REVIEWS.

THE GEOLOGY OF THE SOUTH WALES COALFIELD. Part XIII: THE COUNTRY AROUND PEMBROKE AND TENBY. Being an account of the region comprised in Sheets 244 and 245 of the map. By E. E. L. DIXON, B.Sc., F.G.S. Memoirs of the Geological Survey. pp. i–vi, 1–220, with 5 plates, 12 maps, and 1 section. 1921. Price 8*s.* net.

THIS memoir concludes the series devoted to the description of the maps of the revised survey of the South Wales Coalfield. The introduction contains an admirable account of the physical structure of the area, and is followed by a detailed account of the rocks in the order of their formation. The Lower Palæozoic rocks are found in two important anticlines. Upper and Lower Llanvirn, Wenlock, and Ludlow formations are represented, those of Silurian age being of the type characteristic of South Wales.

The Devonian rocks are of great interest. Both Lower and Upper Old Red Sandstone occur, the former with Pteraspids, the latter with *Holoptychius*. The upper beds are discordant to the lower. In the upper group occur the Skrinkle beds, an interbedded marine and continental series. These Skrinkle beds were briefly noticed in the memoir of the country around Milford in 1916, but full details appear in the present memoir. The marine fauna agrees with that of the Baggy beds, and the containing rocks are, therefore, as surmised by Salter, of Devonian age, even if, as seems to be the case, the Pelton beds must be removed to the Carboniferous system

The Lower Carboniferous beds apparently show a complete succession from "K" to "D 3". The description is based upon the classification of Vaughan, whose labours in these rocks have been so successfully taken up by the author of the memoir, and the account of the rocks is of the utmost importance to students of the system. "Reef-structures" are described in the division C, and the author appears to favour their contemporaneous origin. The Upper Carboniferous rocks are almost entirely referable to the Millstone Grit, a small patch of Coal-measures appearing only at the northern border. The lower part of the Millstone Grit series contains the well-known Radiolarian cherts, and a fauna of part of the Pendleside series. The highest beds have yielded a Westphalian flora.

Of Mesozoic rocks no true deposits are found, but some remarkable "gash-breccias" are almost certainly of Triassic age. They are regarded as due to collapse and infilling of cavities eroded by underground waters.

Certain pipe-clays at Flimston are considered as being of Tertiary age, and probably the equivalent of the Bovey Tracy beds; while certain gravels with quartz pebbles may be relics of Pliocene river-deposits.

A very important chapter is devoted to tectonics. Evidence is given of many periods of earth-movement, greatest stress being laid

upon the Armorican movements, which produced folding, faulting, cleavage, shearing, and jointing. The most important cross-faults give evidence of lateral movement. The Pleistocene accumulations consist of the well-known raised beach, cave-deposits, and glacial accumulations. The raised beach is regarded by Dewey as interglacial, and the existence of glacial deposits older than the beach is "slightly suggested at two places" in this area. The relations of the beach to the cave-deposits with Pleistocene mammals "do not appear to have been established beyond doubt". Glacial deposits newer than the raised beach consist of gravels and loamy and gravelly boulder-clay.

The latest formations are river-terraces, a submerged forest, alluvium, blown sand, and shingle beaches. Much light has been thrown on the organisms and human artefacts of the submerged forest group by the labours of A. L. Leach.

A brief chapter on economics closes the memoir, though, as stated in the Director's preface, "few deposits of economic importance occur within the boundaries" of the district. Notwithstanding this, the work recorded in this and the previous memoirs of the area around the South Wales Coalfield, especially those parts referring to tectonics, will no doubt be of the utmost utility in helping to solve economic problems in the future. These memoirs, indeed, are an admirable illustration of the value of the work of the Survey in aiding economic geology indirectly as well as directly. We feel confident that Dr. Flett's hope "that this district will be recognized by students and teachers of geology as a typical area for the study of the formations represented, as developed in the south-west of Wales," will be fulfilled, and are glad to note that he calls attention to the fact that copies of the 6 in. maps "may be seen at the offices of the Survey, where also the fossils collected may be examined".

Students and teachers, and, indeed, all other geologists, may be congratulated that a district so interesting alike for its physiography and its geology is elucidated by so excellent a memoir. Mr. Dixon has produced a work of high merit, well got up, well illustrated, and at a price that compares favourably with that of some of the memoirs of the latter part of the last century.

J. E. M.

Fluorspar (1913-1919). Imperial Mineral Resources Bureau Digests. pp. 18. 1921. Price 9*d*.

FLUORSPAR has always been a favourite mineral with collectors, mainly on account of the variety and beauty of the specimens obtainable. Its origin also presents problems of much interest to the petrologist and student of ore-deposits. Of late years it has also become of considerable technical importance, as a flux in the making of steel by the basic open-hearth process, in the preparation of electrolytes used in the reduction of aluminium ores, and for